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ABSTRACT

This guide explores the connection between electricity and magnetism with middle level and high school students. The phenomenon of electromagnetism is broken down into four lesson plans that provide students and teachers with a carefully constructed yet easy way to learn about their history. All four activities prompt students to use inexpensive, easily obtained materials such as wires, batteries, magnets, and plastic drinking cups and straws. The first activity evaluates the relationship between electric flow and the magnetism that is produced from that flow. Other activities have students build an electric motor and explore the concept of magnetic interaction, the force behind the workings of modern day electric motors that turn CDs, computer disk drives, and thousands of other devices. This book also incorporates sciLINKS, an innovative National Science Teachers Association (NSTA) resource that provides a link to key Web pages that compliment the activities. The book also incorporates maps from "The Atlas of Science Literacy" and Project 2061 from the American Association for the Advancement of Science (AAAS). These maps help teachers identify a framework for where a student is in terms of standards-based learning goals. (SAH)

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CHARGING AHEAD

An Introduction to Electromagnetism

BY [illegible] E. SCHAFER

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CHARGING AHEAD

An Introduction to Electromagnetism

By Larry E. Schafer

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Acknowledgments

Larry E. Schafer, the author of *Charging Ahead: An Introduction to Electromagnetism*, teaches physical science and elementary science methods courses at Syracuse University, where he has also chaired teaching and leadership programs. His previous work for the National Science Teachers Association (NSTA) was the student-activity book *Taking Charge: An Introduction to Electricity* (1992, 2000). He has directed many funded projects designed to help teachers improve the science education in their schools, has worked with the New York State Education Department to create a statewide system of elementary science mentors, and has co-authored books for middle school science teachers and their students.

The book's reviewers were Chris Emery, a physics teacher at Amherst Regional High School, Amherst, Massachusetts; Dale Rosene, a science teacher at Marshall Middle School in Marshall, Michigan; Daryl Taylor, a physics teacher at Williamstown High School in Williamstown, New Jersey; and Ted Willard, senior program associate at the American Association for the Advancement of Science's Project 2061.

The activities in the book were field-tested by Mark M. Buesing and Suzanne Torrence, both physics teachers at Libertyville High School, Libertyville, Illinois, and Jay Zimmerman, a physics teacher at Brookfield Center High School, Brookfield, Wisconsin.

The book's figures were created by Kim Alberto, Linda Olliver, and Tracey Shipley, from originals by Larry Schafer.

The NSTA project editors for *Charging Ahead: An Introduction to Electromagnetism* were Judy Cusick and Anne Early. Linda Olliver designed the book and the cover. Catherine Lorrain-Hale coordinated production and printing of the book.

Overview

Charging Ahead: An Introduction to Electromagnetism is a set of hands-on activities designed to help teachers introduce middle-level and general high school students to electromagnetism, one of the most fascinating and life-changing phenomenon humankind has witnessed. In 1820, Hans Christian Oersted, a Danish physicist and schoolteacher, discovered that an electrical current produces magnetism. Little did he know that his discovery would have an impact on modern day lives in profound ways: that electrical motors would start cars, turn CDs and disk drives, run can openers, food processors, refrigerators, and clocks, operate pumps for maintaining life support, and run nearly all of the machines that produce and manufacture the many goods upon which we rely. Little did he know that this connection between electricity and magnetism would lead others (Michael Faraday and Joseph Henry) to discover ways of creating electricity from motion and magnetism and in so doing make it possible for human beings the world over to move about, heat and light their environments, and instantly and conveniently communicate.

Charging Ahead uses readily available materials to introduce students to electromagnetism, to the factors that determine the magnetic strength of electrical coils, to the application of electromagnetism in the construction of an electrical motor, and to the production of electricity through the construction of a generator. Throughout *Charging Ahead*, students are introduced to historical perspectives and to technological applications (circuit breakers, mag-lev trains, superconducting generators, etc.) of electromagnetism.

SCILINKS.

Topic: electromagnetism
Go To: *www.scilinks.org*
Code: CH001

Topic: Hans Christian Oersted
Go To: *www.scilinks.org*
Code: CH002

Fitting *Charging Ahead* into Your Curriculum

Charging Ahead is a companion guide to NSTA's *Taking Charge: An Introduction to Electricity.* While students would benefit from experiencing the activities in *Taking Charge*, it is not necessary that students complete *Taking Charge* before attempting the activities in this book. Students will nevertheless need a basic understanding of electrical circuits to understand the ideas presented in *Charging Ahead.*

Key relationships are developed from what students experience in the activities. Abstract formulations and mathematical descriptions, although important, are minimized in *Charging Ahead*. The activities therefore serve as "end points" for middle school students and "starting points" for high school students who are on the path toward understanding abstract formulations of electromagnetism and electromagnetic induction.

Charging Ahead addresses the *National Science Education Standards* in a number of ways. Students learn about energy forms and energy transfer, engineering design and troubleshooting, and science-technology relationships. Students are challenged to solve problems and to think critically and creatively. See p. xii for a Guide to Relevant National Science Education Content Standards.

Organization

The activities in *Charging Ahead* use an inquiry approach to guide student understanding of the concept goals. Each student activity includes an introduction, a description of the materials needed, a statement of what students will learn, and procedures to follow. None of the activities require "high tech" equipment. Wires, flashlight batteries and bulbs, magnets, and magnetic compasses are the basic materials used in the activities.

The procedure section of each activity is designed so that students can perform the activity without the teacher's constant involvement and direction. The procedure section presents students with problems to solve, questions to answer, and tasks to accomplish. It should be clear that students will occasionally face difficulty as they work through the procedures. Underlying the design of these activities is the idea that students will more meaningfully understand the concepts and relationships if they are challenged to figure some things out for themselves.

Each activity is accompanied by a teacher's guide to the activity. The guide is written so that the teacher acquires a brief overview of what will happen in the activity, directions for the construction of equipment and/or the selection of materials, time management recommendations, cautionary notes, ideas for extended activities, and answers to questions.

Assessment Methods

The teacher can use both formative and summative assessment with *Charging Ahead*. The answers that students give to the questions in each activity provide a formative record of their thinking and learning—showing students and the teacher what students understand, what is still fuzzy or missing, and whether students can now use what they know. The suggestions for further study at the end of each activity can be used to extend—and then test—stu-

dents' learning. These extensions are authentic applications of the concepts students have just investigated. You may wish to build an assessment rubric for one or more of the extensions and use it as a summative assessment of your students' mastery of electromagnetism concepts.

Special Considerations

The first and second activities are fairly straightforward. They call on students to examine the relationship between electrical flow and magnetism and investigate how to increase the magnetic forces created by a current-carrying wire. The third and fourth activities challenge students to build an electric motor and an electric generator. Electrical motors and generators built from readily available materials are somewhat temperamental. While each design has been thoroughly tested (75 percent of sixth graders had an electrical motor going in 30 minutes), neither students nor teachers should expect success without some "troubleshooting." Success can be greatly improved by using the recommended materials and by carefully following the directions and suggestions. The need to "troubleshoot" to get things to work should be taken as an opportunity to help students value the creative and persistent work done by engineers who design and debug the devices that reliably work.

Initial construction of motor and generator parts will take some time. Students can help with the construction of those parts. Once the parts are constructed, they can be used repeatedly by different classes of students.

As a consequence of taking part in electricity activities, some students may become very interested in motors, generators, and other electrical devices. They may be inclined to examine these devices on their own in backyards and basements. The investigation of household electrical devices can lead to serious injury. Therefore, please warn students that they should not investigate electrical devices without the help and supervision of a knowledgeable adult.

The activities in *Charging Ahead* are safe since small currents and voltages are used. Short circuits are sometimes used in the activities and these circuits can produce hot wires. Student should be warned to keep short circuits on only for short periods of time (a few seconds). In such short periods of time, the wires wil not significantly heat up nor will batteries quickly wear out.

The four *Charging Ahead* activities build on each other, connecting science content as described in the *Atlas of Science Literacy* map on p. xi. You can compare the concept goals at the start of each activity with your own instructional goals to determine which activity to use.

A Learning Map on Electricity and Magnetism

What Is This Map?

The map on page xi is a way of considering and organizing science content standards. The map uses the learning goals (or parts of them) of the American Association for the Advancement of Science's *Science for All Americans* (1989) and *Benchmarks for Science Literacy* (1993). Content standards from the *National Science Education Standards* (*NSES*) (National Research Council 1996) overlap nearly completely with those goals. Arrows connecting the goals imply that understanding one goal contributes to the understanding of another. Goals that deal with the same idea are organized into vertical "strands," with more sophisticated goals above simpler ones. Descriptive labels for the strands appear at the bottom of the map.

The science content on the map lists the ideas relevant to students' understanding of electricity and magnetism that are both important and learnable. Your students may well learn more, but will learn better after the basic science literacy described on the map has been achieved. This map traces the ideal development of electricity and magnetism knowledge from kindergarten to twelfth grade. Horizontal lines represent the level of grade appropriateness.

Charging Ahead provides instructional methods that primarily achieve learning goals for the map strand labeled "electromagnetic interactions." The map suggests what ideas students must have before trying to examine the relationship between electricity and magnetism. Unit activities as presented may not be sufficient for students to become proficient with some of the basic or extended ideas in the map strand; checking the progress of your students along the way will help you see how to adapt instruction. Unit activities may also touch on concepts outside of what the various science standards consider essential for basic science literacy. Therefore, you may decide to focus activities to make sure your core learning goals are achieved.

How Can I Use the Map?

An *Atlas* map is designed to help clarify the context of the benchmark or standard: where it comes from, where it leads, and how it relates to other standards. With the map as a guide, you can make sure your students have experience with the prerequisite learning, and you can actively draw students' attention to related content—getting their framework for learning ready!

In addition to using the map to plan instruction, you may wish to annotate the map with common student misconceptions to address or common accurate conceptions that you can invoke to dispel these misconceptions. Motivating questions that have worked for you, and phenomena to illustrate points, may also find a place on your annotated map.

The map can help you connect your instruction to your state science standards. As of this writing, 49 of the 50 states in the United States have developed their own standards, most modeled directly on the *National Science Education Standards* or the *Benchmarks for Science Literacy*. The correlation between the *NSES* and *Benchmarks* in science content is nearly 100 percent. So there is a unity of purpose and direction, if not quite a common language. Fortunately, the National Science Foundation, the Council of Chief State School Officers, and other groups have funded and developed websites to guide educators in correlating these national standards with their state goals (e.g., the ExplorAsource website at *www.explorasource.com/educator*. The websites of many state departments of education also provide this correlation service for educators.

The map can also provide a way to think about the design of student assessment . The goal of your summative assessment is to determine whether students can apply their learning to new situations—to show you, and to show themselves, that they have a new tool for understanding.

Are There Other Maps?

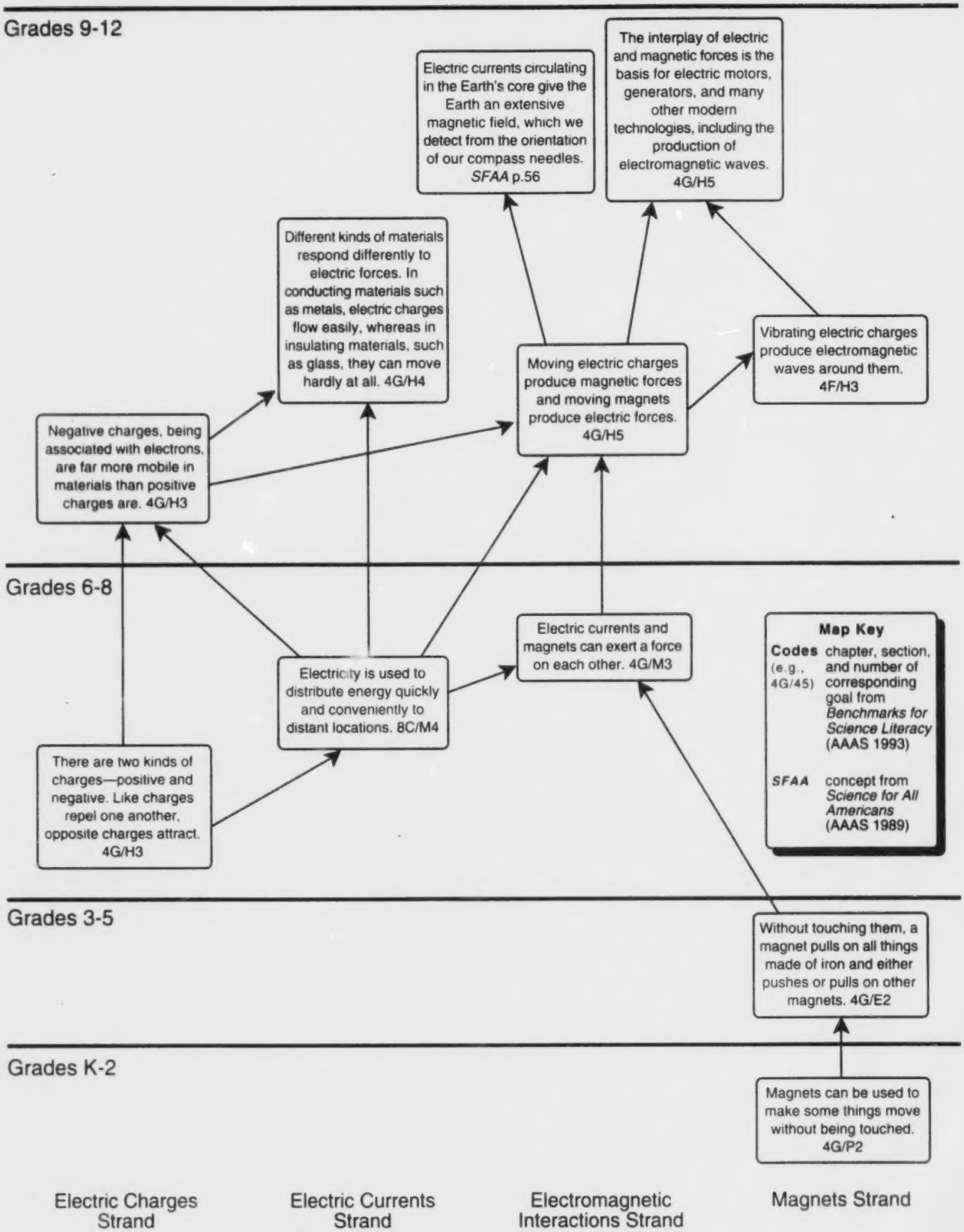
These maps are being copublished by AAAS and NSTA in a new two-volume work, *Atlas of Science Literacy*. The complete *Atlas* will contain nearly 100 similar maps on the major elementary and secondary basic science topics: gravity, cell functions, laws of motion, chemical reactions, ratios and proportionality, and more.

The connected learning goals displayed in *Charging Ahead* are only part of a map that is—at the time of this printing—subject to revision. As additional maps are developed and tested, they will be linked to the *Charging Ahead* page on the NSTA website and added to successive editions of *Charging Ahead*.

Map, Assessment, and the Constructivist Process

Use the map as an aid to your constructivist teaching methods, allowing students to recognize and integrate concepts—either those never learned or those incompletely remembered—into the big picture of why these concepts are useful to know.

Before you undertake any of the four activities in this book, it is important to know whether your students have mastered the principles in the map that lead to their current grade level. You may, for example, be surprised to learn that some of your high school juniors do not really understand that "magnets can be used to make some things move without being touched," a concept that, according to the strand map, should be mastered by grade three. Students may also have a mix of true and false understandings about electricity and magnetism as they begin the *Charging Ahead* activities. It may be wise to ascertain—perhaps by having each student do a "web" of everything he or she can think of about the term "magnetism" and reviewing those webs—to ensure that all students are starting with the basic information they need to build on in order to understand the concepts presented in these activities.


Grades 9-12
Electric currents circulating in the Earth's core give the Earth an extensive magnetic field, which we detect from the orientation of our compass needles. SFAA p.56
The interplay of electric and magnetic forces is the basis for electric motors, generators, and many other modern technologies, including the production of electromagnetic waves. 4G/H5
Different kinds of materials respond differently to electric forces. In conducting materials such as metals, electric charges flow easily, whereas in insulating materials, such as glass, they can move hardly at all. 4G/H4
Vibrating electric charges produce electromagnetic waves around them. 4F/H3
Moving electric charges produce magnetic forces and moving magnets produce electric forces. 4G/H5
Negative charges, being associated with electrons, are far more mobile in materials than positive charges are. 4G/H3
Grades 6-8
Electric currents and magnets can exert a force on each other. 4G/M3
Electricity is used to distribute energy quickly and conveniently to distant locations. 8C/M4
There are two kinds of charges—positive and negative. Like charges repel one another, opposite charges attract. 4G/H3
Map Key
Codes (e.g., 4G/45) chapter, section, and number of corresponding goal from Benchmarks for Science Literacy (AAAS 1993)
SFAA concept from Science for All Americans (AAAS 1989)
Grades 3-5
Without touching them, a magnet pulls on all things made of iron and either pushes or pulls on other magnets. 4G/E2
Grades K-2
Magnets can be used to make some things move without being touched. 4G/P2
Electric Charges Strand
Electric Currents Strand
Electromagnetic Interactions Strand
Magnets Strand

ELECTROMAGNETISM

This map was adapted from *Atlas of Science Literacy* (AAAS 2001). For more information, or to order, go to *www.nsta.org/store*.

Guide to Relevant National Science Education Content Standards

Content Standard*	Activity 1 Introduces the relationship between electrical flow and magnetism.	Activity 2 Builds on student understanding of magnetism and electrical flow by showing how coils in a current-carrying wire affect the strength of magnetic forces.	Activity 3 Challenges students to construct an electric motor using their understanding of electromagnetism.	Activity 4 Challenges students to construct a closed circuit (coil) that moves through a magnetic field to produce or generate electricity.
Unifying Concepts and Processes in Science	■	■	■	■
Science as Inquiry	■	■	■	■
Physical Science	■	■	■	■
Science and Technology	■	■	■	■
History and Nature of Science	■			■

*Source: National Research Council. 1996. *National Science Education Standards.* Washington, DC: National Academy Press, pp.104-107.

Charging Ahead: An Introduction to Electromagnetism brings you *sci*LINKS, a new project that blends the two main delivery systems for curriculum—books and telecommunications—into a dynamic new educational tool for children, their parents, and their teachers. *sci*LINKS links specific science content with instructionally rich Internet resources. *sci*LINKS represents an enormous opportunity to create new pathways for learners, new opportunities for professional growth among teachers, and new modes of engagement for parents.

In this *sci*LINKed text, you will find an icon near several of the concepts you are studying. Under it, you will find the *sci*LINKS URL (*www.scilinks.org*) and a code. Go to the *sci*LINKS website, sign in, type the code from your text, and you will receive a list of URLs that are selected by science educators. Sites are chosen for accurate and age-appropriate content and good pedagogy. The underlying database changes constantly, eliminating dead or revised sites or simply replacing them with better selections. *sci*LINKS also ensures that the online content teachers count on remains available for the life of this text. The *sci*LINKS search team regularly reviews the materials to which this text points—revising the URLs as needed or replacing webpages that have disappeared with new pages. When you send your students to *sci*LINKS to use a code from this text, you can always count on good content being available.

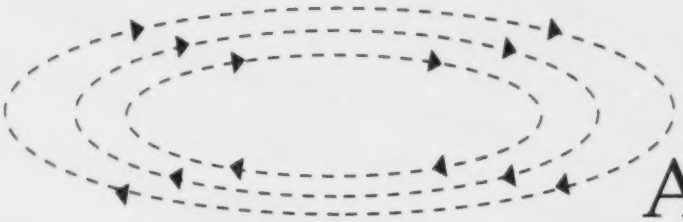
The selection process involves four review stages:

1. A cadre of undergraduate science education majors searches the World Wide Web for interesting science resources. The undergraduates submit about 500 sites a week for consideration.
2. Packets of these webpages are organized and sent to teacher-webwatchers with expertise in given fields and grade levels. The teacher-webwatchers can also submit webpages that they have found on their own. The teachers pick the jewels from this selection and correlate them to the *National Science Education Standards*. These pages are submitted to the *sci*LINKS database.
3. Scientists review these correlated sites for accuracy.
4. NSTA staff approve the webpages and edit the information for accuracy and consistent style.

*sci*LINKS is a free service for textbook and supplemental resource users, but obviously someone must pay for it. Participating publishers pay a fee to NSTA for each book that contains *sci*LINKS. The program is also supported by a grant from the National Aeronautics and Space Administration (NASA).

Activity 1

Student Worksheet



A Bonus from Electrical Flow—Magnetism

Background

When you create a closed circuit with a battery, electrons flow through the wires, the bulb lights up and gets hot, and the wires and battery warm up. Besides the chemical reactions going on inside the battery, is anything else happening? It is hard to tell unless you can use some detection device. In this investigation, you will use a compass to detect magnetism. You will use the compass to investigate the relationship between electrical flow and any magnetism that is produced from that flow.

SCILINKS

Topic: electrical circuit
Go To: www.scilinks.org
Code: CH003

Topic: magnetic effect
Go To: www.scilinks.org
Code: CH004

Concept Goals

- A current-carrying wire produces a magnetic effect (deflects a compass needle) in the region around the wire. That magnetic effect is called *electromagnetism*.
- Electrons move along a wire from the negative end of the battery to the positive end of the battery.
- The direction of the electron flow in a wire determines the direction of the magnetic field around the wire.
- The strength of the magnetic influence (field) around a wire becomes less at greater distances from the wire.
- Magnetic fields (regions of magnetic influence) have direction and "strength."
- The direction of the magnetic field at a particular point in space is the direction a compass needle would point if the compass were located at that point.

Materials

For each group:

- *one "D" battery (dry cell) and one battery holder*
- *one directional, magnetic compass with a needle that is free to move easily without sticking*
- *one 60-cm piece of #24 enamel-coated (insulated) wire (with sanded ends) or #22 plastic-coated wire (with stripped ends)*

- A left hand is an effective model for showing the relationship between the direction of the magnetic field and the direction of electron flow.

Procedure

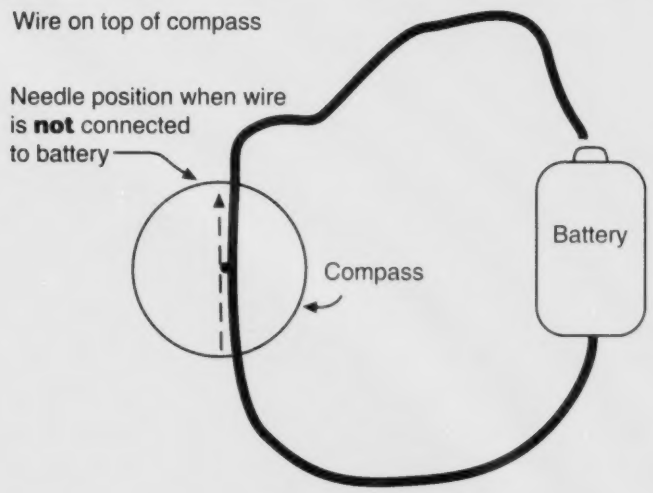
1 If you have not used a compass recently, you may want to refresh your memory. The colored or pointed end of the needle usually points approximately toward the Earth's geographic north. Hold the compass out in front of you, away from any metal objects, and note that the colored or pointed end of the needle always points in the same direction, even when you rotate the base or case of the compass.

Move your compass close to an iron or steel object and notice that the compass needle is attracted to the object. It is important, therefore, to keep the compass away from iron or steel objects when you are using it to detect magnetism from other objects. Iron or steel under the desktops can influence the direction in which the compass needle points.

The compass needle is nothing more than a small, light magnet that easily spins about its center when it interacts with other magnets. The compass needle is attracted to iron and steel objects because the needle itself causes those objects to become temporarily magnetized.

2 In 1820, Hans Christian Oersted, a Danish physicist and schoolteacher, made the observation you are about to make. His discovery set the stage for the development of many modern conveniences, including electrical motors and the generation of electricity from motion.

Figure 1.1

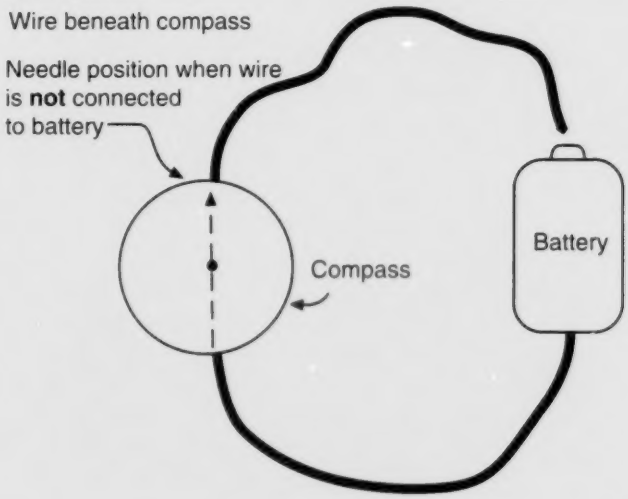


a Place the compass on the table at least 15 cm away from the battery. Connect one end of the wire to the battery. Place the wire in a straight line directly over the compass and in line with the needle. Briefly touch (no more than two seconds) the other end of the wire to the battery and observe what happens to the compass needle.

Draw an arrow on the compass illustration in Figure 1.1 to show the direction of the needle

when a current-carrying wire is *on top of* the compass. The pointed end of the arrow represents the "north-seeking" end of the needle. Also draw an arrow on the wire showing the direction in which the electrons are moving in the wire. Recall that electrons move along a wire from the negative end of the battery to the positive end of the battery.

Figure 1.2



b Repeat the above activity, but this time place the wire *under* the compass and align the wire with the compass needle. Draw an arrow on the compass drawing (Figure 1.2) to record the direction of the needle when a current-carrying wire is *under* the compass. Also, draw an arrow showing the direction of electron flow in the wire. Remember to keep the electricity flowing in the wire for only two seconds.

c Note the direction in which the needle moved ("deflected") in 2b above. With the wire under the compass and without changing the positions of the compass or the wire, what can you do to make the deflected needle point in the opposite direction? Describe your solution in the space below.

d It should be clear that a current-carrying wire is somehow creating a magnetic influence in the space around it. What can you do to find out how the "strength" of that influence changes with different distances from the wire? Describe your solution, your conclusion about distance and "strength," and how your observations support your conclusion.

e A magnetic field is a region of space in which there is a magnetic influence. There is a magnetic field in the space around a magnet. A compass can detect a magnetic field if the field is strong enough. Because the compass needle is deflected in the region around the current-carrying wire, you can conclude that there is _____ _____ around a current-carrying wire.

f Magnetic fields have both "strength" and direction at each point in space. The direction is the direction that a compass will point if it is held at that point in space. The magnetic field both above and below a current-carrying wire is: (circle 1 or 2)

1 in line with the wire.

2 across the wire.

g To change the direction of the magnetic field above a wire, you would have to change the _____ of the electron flow in the wire. Without moving the wire above the compass, you can do this by

_____.

h The magnetic field around a current-carrying wire is "stronger": (circle 1 or 2)

1 closer to the wire.

2 farther away from the wire.

3 You can use your left hand as a model of the relationship between the direction of the electron flow and the direction of the magnetic field (the direction the compass would point) created by that flow.

A Left-hand Model

Pretend to grasp the wire with your left hand. Wrap your fingers around the imaginary wire in such a way that your left thumb points in the direction of electron flow (Figure 1.3). Your fingers will then wrap around the wire in the direction of the magnetic field. You can rotate your hand around the wire to see which way your fingers point at any position around the wire (Figure 1.4).

Practice using the left-hand model by answering the following questions associated with Figure 1.5. (circle the correct answer)

a The magnetic field directly *above* the wire at "a" would point:

1 to the left.

2 to the right.

3 straight up out of the page.

4 straight down into the page.

Figure 1.3

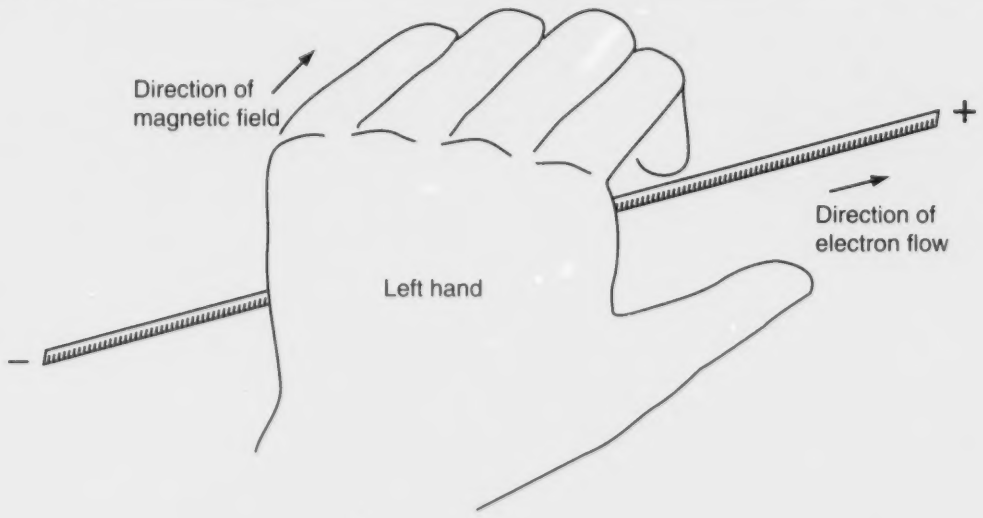


Figure 1.4

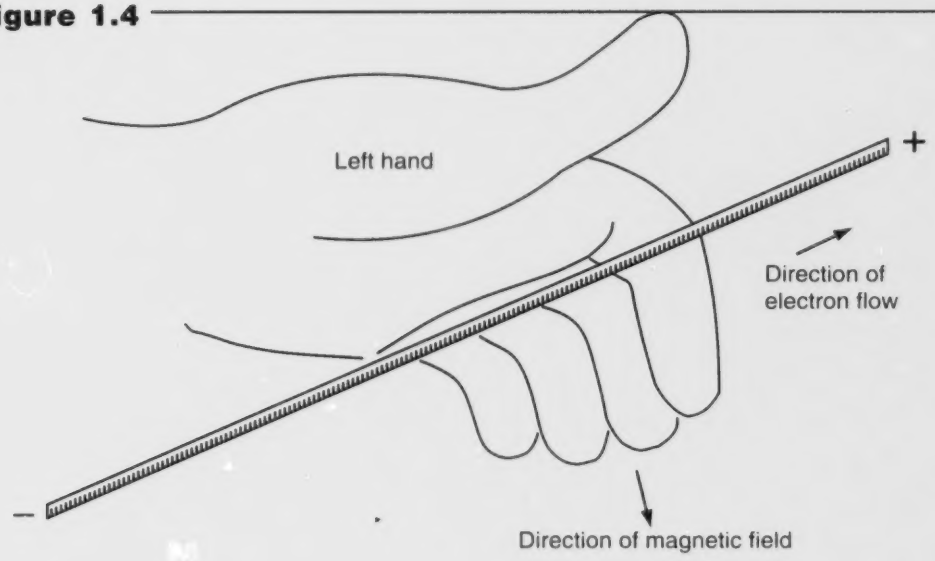
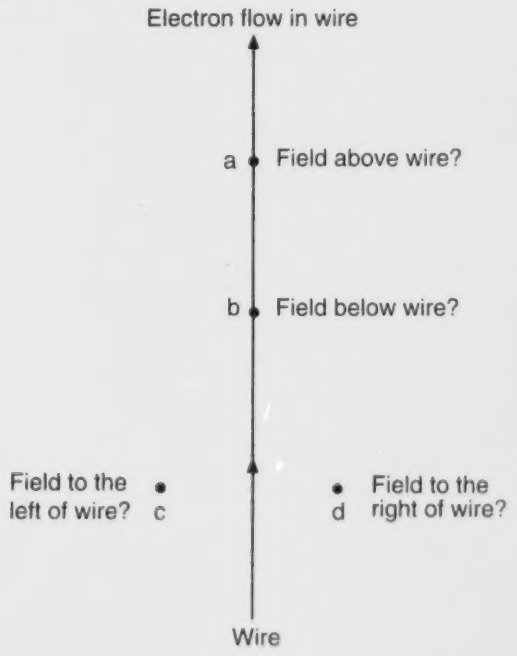


Figure 1.5



b The magnetic field directly *below* the wire at "b" would point:

1 to the left.

2 to the right.

3 straight up out of the page.

4 straight down into the page.

c The magnetic field directly *to the left* of the wire (neither above nor below the wire) at "c" would point:

1 to the left.

2 to the right.

3 straight up out of the page.

4 straight down into the page.

d The magnetic field directly *to the right* of the wire (neither above nor below the wire) at "d" would point:

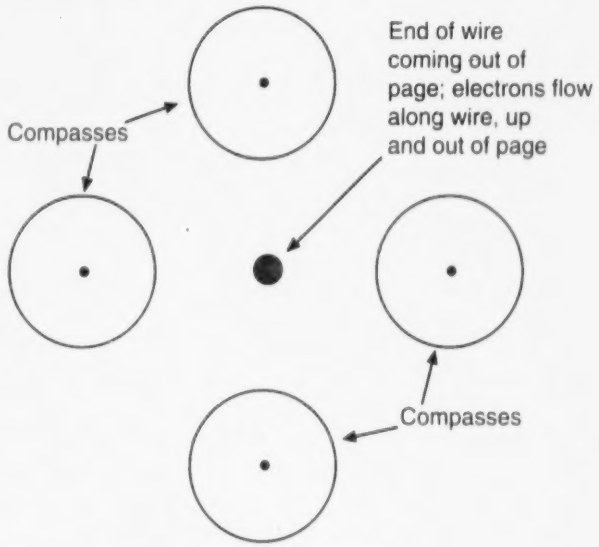
1 to the left.

2 to the right.

3 straight up out of the page.

4 straight down into the page.

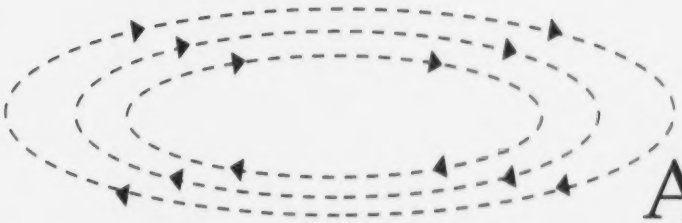
Figure 1.6



e Observe Figure 1.6 and assume that the dot in the center is the end of a wire that is coming out of the page. Further assume that electrons are flowing along that wire out of the page directly upward from the page. Use your left-hand model to determine the direction of the compass needle (direction of the magnetic field) at each of the compass points around the wire. Draw the compass needles in the four compasses and use the pointed head of the arrow as the "north-seeking" end of the compass needle.

Teacher's Guide To

Activity 1



A Bonus from Electrical Flow—Magnetism

What is happening?

In this activity, students discover that a current-carrying wire produces a magnetic field around it. They use a compass to detect this magnetic field, and they observe that the direction of the field is across the direction of the electron flow. Furthermore, the students learn that the field is "stronger" closer to the wire. In addition, the students learn that the direction of the magnetic field at a point in space is described as the direction the north-seeking end of a compass would point. Students can use their left hands to model the relationship between the direction of the electron flow and the direction of the magnetic field it produces. Students practice applying the model to different examples.

Time management

One class period (40–60 minutes) should be enough time to complete the activity and discuss the results.

Preparation

Collect the materials listed on page 2. Make sure that the batteries are not dead, that the compasses work, and that the ends of the wires are stripped (plastic-coated wire) or sanded (enamel-coated wire). If the students have not worked with enamel-coated wire, show them how to use sand paper to sand off the enamel from the ends of the wires.

Students may find that their compasses point in different directions without any current-carrying wires or magnetic materials nearby. Why don't all the compasses point north? Why do the compasses point in different

Caution

Short circuits are created when the wire is connected to the ends of the battery. The short circuit will heat up the wire and quickly wear down the battery. Caution the students to maintain a short circuit for only a couple of seconds at a time. They can do this by connecting one end of the wire to the battery and briefly touching the other end of the wire to the battery.

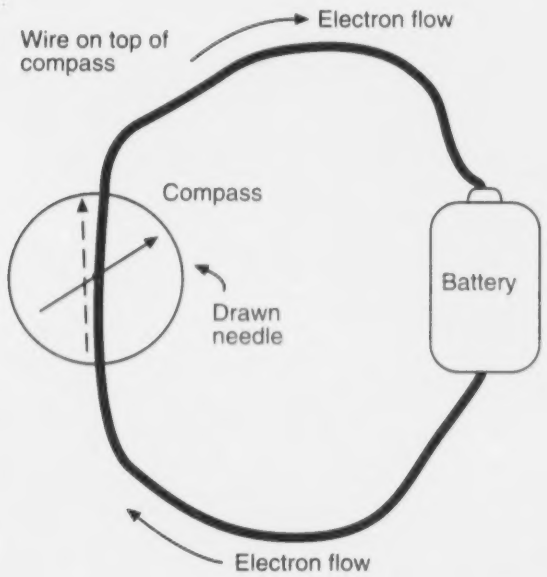
directions when they are moved around on the desks or in the room? Often the iron or steel in desks, filing cabinets, walls, etc. influences the direction of the compasses. For an accurate "north reading," a compass must be away from all iron and steel objects.

Suggestions for further study

Challenge groups to get together to see what happens when two current-carrying wires are held in line with a compass needle. Students should discover that when both wires carry electrons in the same direction over and in line with a compass needle, the needle deflection is greater than when just one wire is used. Students also should discover that when the wires carry electrons in opposite directions over and in line with the compass needle, the needle deflection is less because the magnetic fields exert forces on the needle in opposite directions.

Students have studied direct current electricity where the electrons move in one direction in the conductor. Alternating current electricity is used in our homes. The electrons in the alternating currents switch directions 60 times each second. If this electron jiggling is going on in the wires in our homes, what is happening to the magnetic field surrounding those wires? Have students consider this question and guide them to understand that the magnetic field around the wires in our homes must be jiggling or changing directions 60 times each second. When held near a current-carrying house wire, a typical compass needle does not show deflection. The inertia of the needle prevents the needle from changing directions 60 times each second. Just as the needle begins to move in one direction, it is forced in the opposite direction.

Figure 1.7



Answers *to questions found within Procedure on pages 2–7.*

2a. *Draw an arrow on the compass in Figure 1.1 to show the direction of the needle when a current-carrying wire is* ***on top of the compass.*** *Also draw an arrow showing the direction of electron flow in the wire.*

One answer is shown in Figure 1.7. If the terminals of the battery

were reversed, the drawn arrow would be deflected to the other side of the wire.

2b. *Draw an arrow on the compass in Figure 1.2 to record the direction of the needle when a current-carrying wire* ***is under the compass.*** *Also, draw an arrow showing the direction of electron flow in the wire.*

One answer is shown in Figure 1.8. If the terminals of the battery were reversed, the drawn arrow would be deflected to the other side of the wire.

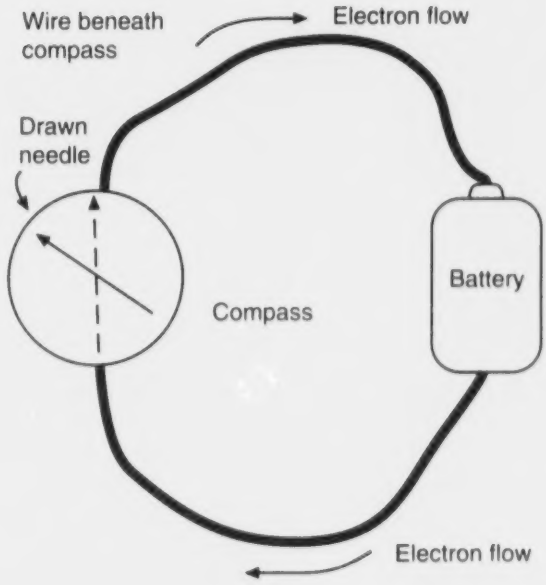
2c. *Note the direction in which the needle moved ("deflected") in 2b above. With the wire under the compass and without changing the positions of the compass or the wire, what can you do to make the deflected needle point in the opposite direction?*

The solution is to keep the wires and compass the same, but switch wires on the terminals of the battery. This sends the electrons in the opposite direction through the wire.

2d. *What can you do to find out how the "strength" of the magnetic influence around the current-carrying wire changes at different distances from the wire? Describe your solution, your conclusion about distance and "strength," and how your observations support your conclusion.*

Change the distance between the current-carrying wire and compass. Note that there is greater deflection in the compass when the wire and compass are closer. Assuming that more deflection means a "stronger" interaction, the conclusion is that the magnetic influence is "stronger" closer to the wire.

Figure 1.8



2e. *When a compass needle is deflected in the region around a current-carrying wire, you can conclude that there is* ***a magnetic field*** *around the wire.*

2f. *The magnetic field both above and below a current-carrying wire is: (1) in line with the wire or (2) across the wire?*

(2) across the wire.

2g. *To change the direction of the magnetic field above a wire, you would have to change the* ***direction***

of the electron flow in the wire. Without moving the wire above the compass, you can do this by ***switching the ends of the wire on the terminals of the battery.***

2h. *The magnetic field around a current-carrying wire is "stronger": (1) closer to the wire or (2) farther away from the wire.*

(1) closer to the wire.

3a. *The magnetic field directly above the wire at "a" would point: (1) to the left, (2) to the right, (3) straight up out of the page, or (4) straight down into the page.*

(1) to the left.

3b. *The magnetic field directly below the wire at "b" would point: (1) to the left, (2) to the right, (3) straight up out of the page, or (4) straight down into the page.*

(2) to the right.

3c. *The magnetic field directly to the left of the wire (neither above nor below the wire) at "c" would point: (1) to the left, (2) to the right, (3) straight up out of the page, or (4) straight down into the page.*

(4) straight down into the page.

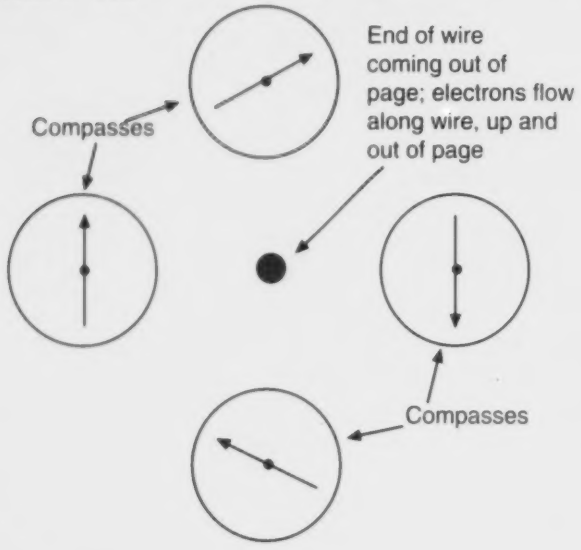
3d. *The magnetic field directly to the right of the wire (neither above nor below the wire) at "d" would point: (1) to the left, (2) to the right, (3) straight up out of the page, or (4) straight down into the page.*

(3) straight up out of the page.

3e. *Observe Figure 1.6 and assume that the dot in the center is the end of a wire that is coming out of the page and that electrons are flowing along that wire directly upward from the page. Use the left-hand model to determine the direction of the compass needle at each of the compass points around the wire. Draw the compass needles in the compasses; use the pointed head of the arrow as the "north-seeking" end of the compass needle.*

The compass directions are shown in Figure 1.9.

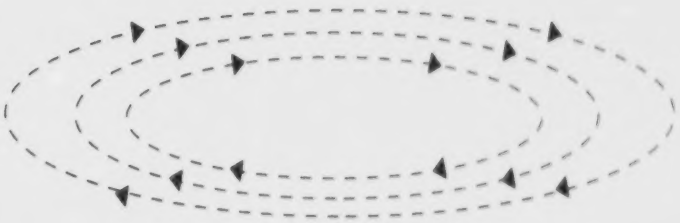
Figure 1.9



Note: *The left-hand model is the same as the right-hand rule found in physics textbooks. Here, the direction of electron flow is used. The right-hand rule uses current direction (positive charge flow).*

Activity 2

Student Worksheet



Coils and Electromagnets

Background

Hans Christian Oersted was probably very excited about his discovery that a current-carrying wire produces a magnetic effect in the region around that wire. Perhaps he realized that current-carrying wires could produce very strong magnetism that may be able to exert forces to turn wheels and accomplish work. All of modern day electric motors depend on the production of magnetism from current-carrying wires. In this activity, you will investigate how to make the magnetism from current-carrying wires stronger. In the next activity you will use an electromagnet to make an electric motor.

SCILINKS
THE WORLD'S A CLICK AWAY

Topic: electromagnet
Go To: *www.scilinks.org*
Code: CH005

Concept Goals

- A coil of wire that carries a current produces a stronger magnetic field than just a straight wire that carries the same current.
- A piece of iron (e.g., a nail) placed in a coil that carries a current will become magnetized by the coil.
- A piece of magnetized iron in a coil that carries a current will produce a stronger magnetic field than just the coil alone.
- An electromagnet is a magnet that is produced by a coil that carries an electrical current.

Materials

For each group:

- *one "D" battery (dry cell) and one battery holder*
- *one 80-cm piece of enamel-coated (insulated) wire (with sanded ends) or bell wire (with stripped ends)*
- *one 20-cm piece of enamel-coated (insulated) wire (with sanded ends) or bell wire (with stripped ends)*
- *three plastic drinking straws*
- *two pieces of masking tape*
- *one large, steel paper clip (4.8 cm x 1 cm)*
- *twenty large, steel paper clips chained together*
- *one steel or iron nail (8–10 cm long)*
- *one beaker, or a foam or plastic cup*
- *one light bulb in its socket*
- *scissors*

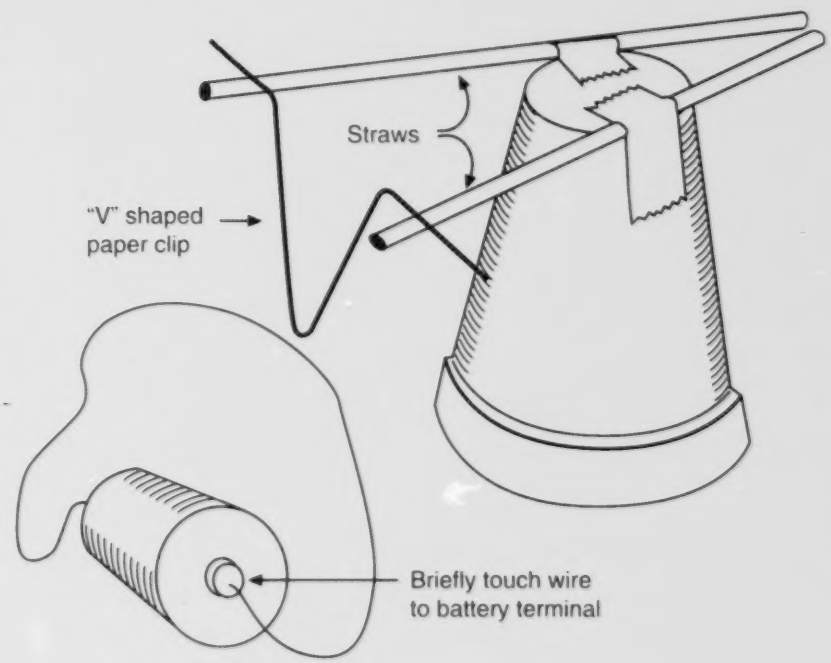
- The strength of an electromagnet increases as the number of wraps in the coil increases.
- The strength of an electromagnet decreases as the electrical current in the coil decreases.

Procedure

1 In the last activity, you deflected a compass needle with a current-carrying wire. Because a current-carrying wire acts like a magnet (it produces a magnetic effect in the region around it), perhaps the wire will attract iron objects just as a regular permanent magnet does.

a Tape two plastic drinking straws to the bottom of an overturned cup or beaker. The ends of the straws should be about 8 cm apart. Open the large paper clip and bend it into a "V" shape as shown below. Place the "V" shaped paper clip on the "arms" of the drinking straws so that it easily moves back and forth (Figure 2.1).

Figure 2.1



b Attach one end of the 80-cm wire to one end of the battery. Use your fingers to stop the paper clip from swinging back and forth. Move the wire very near the bottom part of the "V" (again, see Figure 2.1). Don't touch the paper clip. When the wire is very close to the stationary paper clip, *briefly* touch the other end of the wire to the battery to send a current through the wire. Is the paper clip attracted to the current-carrying wire? Write your answer below.

Caution

A short circuit is created when the wire is attached to the battery. The wire gets hot. Do not allow the ends of the wire to touch the battery for more than two seconds at a time.

c Starting about 8 cm from one end of the wire, wind the wire around your index finger. Be careful not to wind too tightly. Stop winding when you are about 8 cm from the other end of the wire and slip the coil of wire off your finger. Keep the coil together.

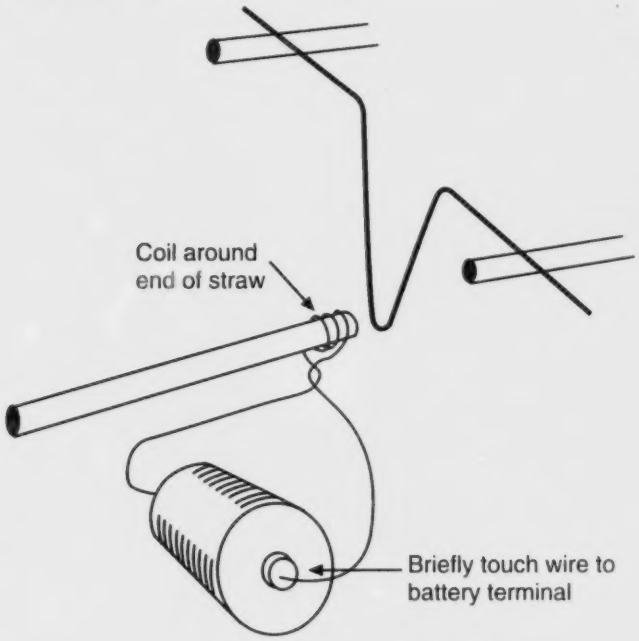
Attach one end of the wire to one end of the battery. Again use your fingers to stop the paper clip from swinging back and forth. Move the coil very near the bottom part of the "V." Don't touch the paper clip. When the coil is very close to the stationary paper clip, briefly touch the other end of the wire to the battery to send a current through the coil. Is the paper clip attracted to the current-carrying coil? How does the coil's attraction compare to the attraction of a single strand of wire? Write your answers below.

d Disconnect the wire from the battery and unwrap the coil of wire. **Do not pull on the ends of the wire to straighten out the coil; this will produce a kinky mess.**

Next, starting about 8 cm from the end of the wire, wrap the wire around a drinking straw (Figure 2.2). Try to keep all the coils within a 1-cm section of the straw. Keep the coil rather tight but do not wrap so tightly

that the straw is crushed. Stop wrapping when there are about 8 cm of wire left. Next, use the scissors to cut one end of the straw close (0.3 cm) to the coil.

Figure 2.2



Connect one end of the wire to one of the battery terminals. Stop the "V" from moving. Move the coil near the end of the bottom of the "V." *Briefly* touch the other end of the wire to the other terminal of the battery to send a current through the coil. Describe below the extent to which the current-carrying coil attracts the "V" paper clip.

Next, place the nail into the end of the straw near the coil. Hold the head of the nail near the "V" and briefly send a current through the coil. How does the coil-and-nail's attraction of the "V" compare to the coil's attraction alone? Write your answer below.

2 When you wrap an insulated current-carrying wire around an iron or steel object, you create an electromagnet. As you found in step 1d above, the iron or steel can greatly increase the magnetic force exerted on nearby objects. The magnetism created by the coil turns the nail into a temporary magnet. For electromagnets to be of any use, they must be able to create rather large magnetic forces. The question arises: How can we increase the strength of an electromagnet?

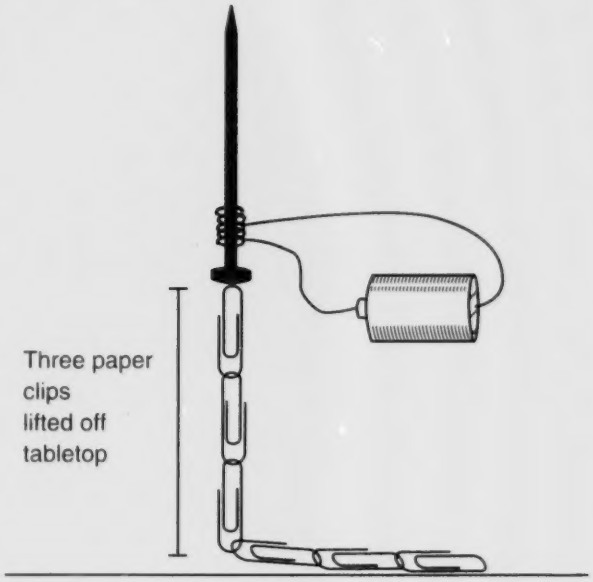
Challenge: Use the nail, the battery, and the chain of 20 paper clips to investigate how the number of coils wrapped around the nail determines the strength of the electromagnet (the number of paper clips lifted off the table).

Keep the coils near the head of the nail.

Stretch out the chain of paper clips on the table.

Use the head of the nail to pick up the first paper clip in the chain. Smoothly move the nail (with the first paper clip attached) over the second paper clip and try to pick two paper clips off the table (Figure 2.3). Keep moving down the chain to see how many paper clips the electromagnet will pick off the table. Keep the nail vertical and in line with the string of paper clips that have been picked off the table.

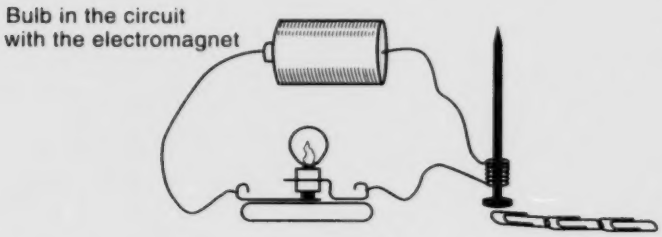
Figure 2.3



Now wrap some more coils around the nail and follow the same steps as above.

Conclusion: In the space below, describe the relationship between the number of coils in an electromagnet and the strength of the electromagnet.

Figure 2.4



3 Construct an electromagnet that will consistently pick up at least three paper clips from a chain of paper clips on the tabletop.

Next, place a light bulb and socket in the circuit, as shown in Figure 2.4. Use the electromagnet to try to pick up at least three paper clips along the chain.

a Describe below how the bulb in the circuit with the electromagnet influenced the strength of the electromagnet.

b When the bulb was placed in the circuit with the electromagnet, the bulb provided resistance to the flow of electricity and caused the electrical flow to be reduced in all parts of the circuit. In other words, the bulb reduced the rate of electrical flow or current through the electromagnet. How does the current (rate of electrical flow) in an electromagnet determine the strength of the electromagnet?

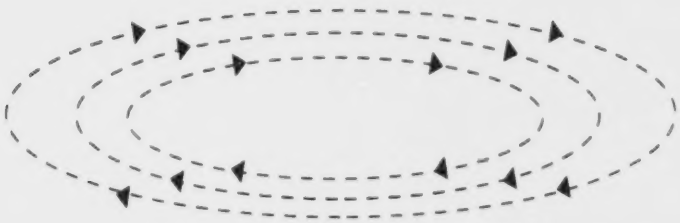
Summarize

c List the factors found in this activity that influence the strength of an electromagnet.

d Describe the relationship between each factor and the strength of the electromagnet.

Teacher's Guide To

Activity 2



Coils and Electromagnets

What is happening?

In this activity, students learn that a current-carrying wire is not only able to show magnetic effects by deflecting compass needles, but, like regular, permanent magnets, it is able to attract iron and steel objects. Additionally, students discover that magnetic forces increase when the number of wraps, coils, or windings in an electromagnet increases and when the current in the coils increases.

Time management

One or two class periods (40–60 minutes each) should be enough time to complete the activity and discuss the student responses.

Preparation

Collect the materials listed on page 14. Make sure that the ends of the wires are sanded or stripped. Also, because the batteries must be rather "strong" for this activity, the batteries should be checked. If the batteries are weak, it may be necessary to provide each group with two batteries hooked up in series.

Suggestions for further study

Electromagnets are used in many different places throughout the home. There are electromagnets in every electric motor (e.g., disk, CD, and tape drives; can openers; fans; electric toothbrushes; garage door openers). Electromagnets also are used in sound speakers (e.g., headsets, phones, radios).

There are electromagnets that protect our homes from fires that are caused by overheated wires in electrical systems. The protection devices are called *circuit breakers*, and they break or open circuits when the current becomes great enough to heat the wires to dangerous temperatures. Figures 2.5 and 2.6 show the basic

Caution

The students will be creating short circuits with their electromagnets and there is a danger that the wires and battery will get hot. Remind the students to disconnect their batteries from the electromagnet as soon as they have made an observation or as soon as the wire begins to get warm.

Figure 2.5

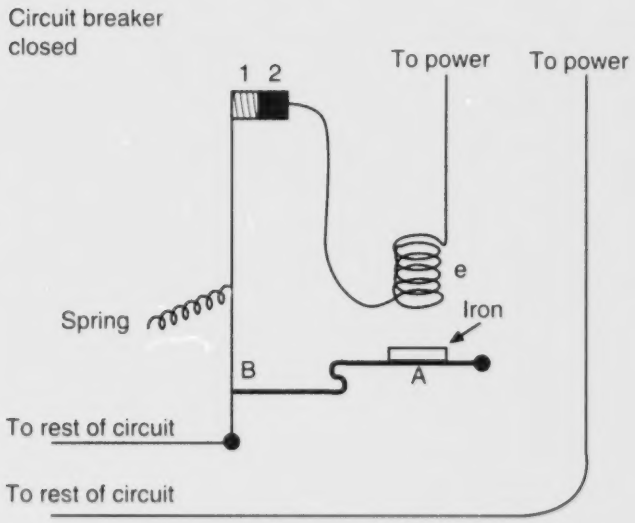
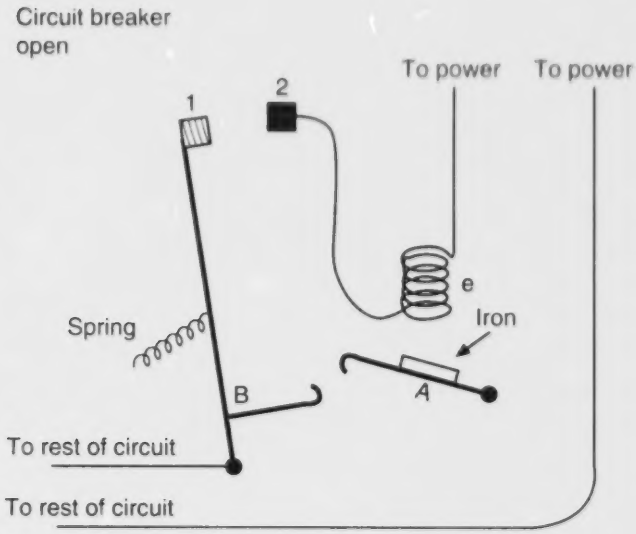


Figure 2.6



workings of the circuit breaker. The more current that runs through the circuit, the stronger the pull of the electromagnet (e). If the current gets too high, the electromagnet becomes strong enough to pull open lever A. This allows lever B to spring backward and open the circuit at 1 and 2. To reset the switch, lever B has to be pushed back to where it connects with lever A and closes the circuit at 1 and 2.

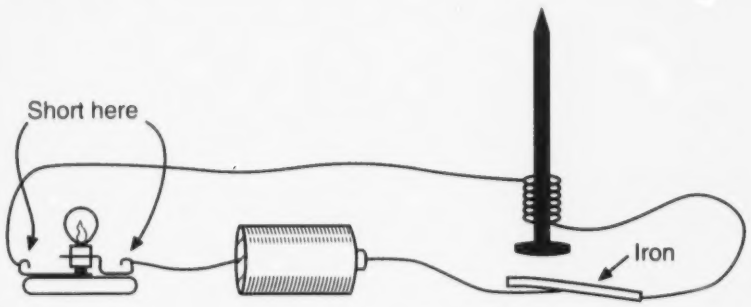
Challenge: Have students create their own circuit breakers using batteries, bulbs, wires, nails, tape, paper clips, etc. They can test their circuit breakers by shorting around the bulb in the circuit. To short around the bulb, use a 20-cm wire to connect the two terminals of the bulb holder (Figure 2.7). The short should greatly increase the current and the increased current should strengthen the electromagnet that pulls open the switch and breaks the circuit.

However, as soon as the circuit is opened, the electromagnet should stop pulling. Without the pull of the electromagnet, the circuit *may* close again. If the circuit does close again, the electromagnet will turn on and reopen the circuit. This circuit, which repeatedly opens and closes, is the type of circuit found in doorbell buzzers.

Because it would be unwise to allow a circuit breaker to close the

circuit immediately after breaking it, the student inventors will have to design a way to keep the circuit open once the electromagnet opens the circuit and turns off the electromagnet. In real circuit breakers, the electromagnet pulls on a trigger that releases a spring-loaded switch. The spring holds the switch open until it is reset.

Figure 2.7



Answers *to questions found within Procedure on pages 14–19.*

1b. *Attach one end of the 80-cm wire to one end of the battery. Move the wire very near the bottom part of the "V" of the paper clip. Briefly touch the other end of the wire to the battery to send a current through the wire. Is the paper clip attracted to the current-carrying wire?*

If the batteries are new, students may see a very slight movement of the paper clip. Most likely the magnetic force from one strand of wire will not be great enough to move the paper clip.

1c. *Attach one end of the wire to one end of the battery. Move the coil very near the bottom part of the "V" of the paper clip. Briefly touch the other end of the wire to the battery to send a current through the coil. Is the paper clip attracted to the current-carrying coil? How does the coil's attraction compare to the attraction of a single strand of wire?*

The coil should attract the paper clip, but not strongly. The attraction from the coil, however, should be greater than the attraction from just one strand of wire.

1d. *Connect one end of the wire to one of the battery terminals. Move the coil near the end of the bottom of the paper clip "V." Briefly touch the other end of the wire to the other terminal of the battery to send a current through the coil. Describe the extent to which the current-carrying coil attracts the paper clip.*

The coil wrapped on the drinking straw should slightly attract the paper clip.

Next, place the nail into the end of the straw near the coil. Hold the head of the nail near the "V" and briefly send a current through the coil. How does the coil-and-nail's attraction of the "V" compare to the coil's attraction alone?

The nail placed inside the straw and coil should produce a significantly greater attraction than the coil alone.

2. *How can we increase the strength of an electromagnet?*

   As the number of coils or windings increases, the strength of the electromagnet increases. (The number of paper clips picked up by the electromagnets also depends on whether the battery is in good condition or not.)

3a. *Describe how the bulb in the circuit with the electromagnet influenced the strength of the electromagnet.*

   When a bulb is placed in the circuit with an electromagnet, the strength of the magnet decreases.

3b. *How does the current (rate of electrical flow) in an electromagnet determine the strength of the electromagnet?*

   Lesser current produces a weaker electromagnet. A greater current produces a stronger electromagnet.

3c. *List the factors found in this activity that influence the strength of an electromagnet.*

   The primary factors that influence the strength of an electromagnet are the number of coils and the rate of electrical flow (current).

3d. *Describe the relationship between each factor listed above and the strength of the electromagnet.*

   Increases in either will result in a stronger electromagnet. Also, an iron core (such as a nail) inside a coil greatly increases the strength of magnetism.

TECHNOLOGICAL TIE-IN

Mag-lev Trains and MRIs

Electromagnets are used in some of the newest technology being developed today. One project is the development of mag-lev ("magnetic levitation") trains. These trains do not ride on wheels; in fact the train does not even touch the track. Strong electromagnets keep the train near the track but off the track. Strong electromagnets also propel the train down the track. Without the friction of rolling wheels on hard track, the mag-lev trains will be able to travel faster (300 miles per hour) and with less energy and less pollution than the trains of today.

Magnets attract iron objects and attract or repel other magnets without touching them. Levitation occurs when an object is held up without touching another object. When magnets are involved in producing levitation, we call that "magnetic levitation." Mag-lev trains hold up and propel the train with electromagnets.

Ordinary electromagnets would not be strong enough to run mag-lev trains and would require a great deal of energy. Superconductors are used in making the very strong magnets needed to run mag-lev trains. Superconductors are materials that have no electrical resistance to the flow of electricity. Without electrical resistance, very strong magnets can be produced. Certain materials become superconductors at very low temperatures. The materials have to be kept cold and this requires energy. Scientists and engineers are working hard to create materials that become superconductors at higher temperatures.

MRI (magnetic resonance image) machines are used in hospitals to take very detailed pictures of tissues inside the body. These machines make images by producing strong magnetic fields through which the body moves. The strong magnetic fields are produced by strong electromagnets that are made with superconducting coils. These machines help doctors diagnose and treat disease. Again, electromagnets are used in new ways that improve our lives.

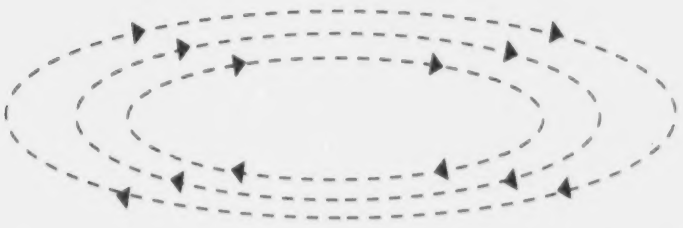
SCILINKS.

Topic: mag-lev trains
Go To: *www.scilinks.org*
Code: CH006

Topic: MRI
Go To: *www.scilinks.org*
Code: CH007

Activity 3

Student Worksheet



Making an Electric Motor—Electromagnetism in Action

Background

The last activity focused on electromagnetism and factors that determine the strength of magnetic interaction. Scientists and engineers have used their knowledge of electromagnets to create simple electromagnetic devices (doorbells, switches, circuit breakers, sound speakers, etc.) that are very much a part of our everyday lives. One of the more complex, ingenious, and useful devices is the electric motor. Electric motors are all around us, turning VCR tapes, CDs, computer disk drives, can openers, toothbrushes, refrigerator and air conditioner pumps, drills, saws, fans, and more. Each electric motor turns because of electromagnets and electromagnetic interaction. In this activity, you will build an electric motor out of common materials, including plastic drinking cups, wire, batteries, plastic drinking straws, and magnets. Although the motor you build will not be able to accomplish much, it should provide you with a basic understanding of how real electric motors work. You will learn that "timing is everything." Furthermore, as you persist in getting your motor to work, you may understand better the persistence and problem solving required to create a useful product that works reliably.

Your teacher will either provide you with the rotor, flopper switch, and penny switch for this activity or guide you through constructing them.

SCILINKS

Topic: electric motor
Go To: www.scilinks.org
Code: CH008

Materials

For each group:
For Part 1—the "strobe" light

- *one rotor on its stand (see Figure 3.1)*
- *one flopper (with washer) (to make a flopper, see page 42)*
- *one penny switch (with wires attached) (to make a penny switch, see page 39–42)*
- *two 1.5-volt dry cells in dry cell holders*
- *one light bulb in a socket*
- *two 15-cm wires*
- *masking tape*

Concept Goals

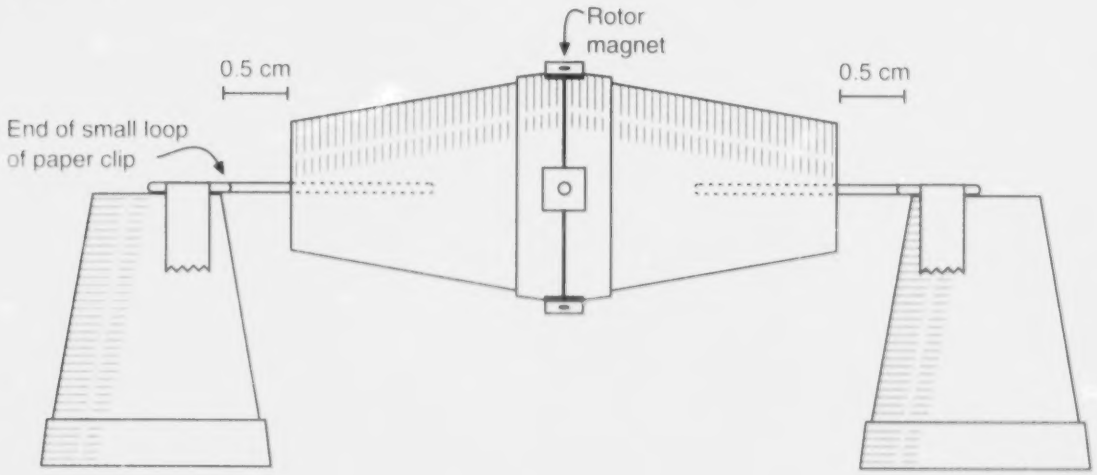
- An electric motor can be built from available simple materials (magnets, wire, batteries, cups, etc.).
- Electric motors work because of the interaction between electromagnets or because of the interaction between electromagnets and permanent magnets.
- Rotors are what move in motors and the rotors are pushed around because the magnets on them interact with other magnets in the motor.
- For electric motors to work, electromagnets must turn on and off at just the right times.

Part 1—Building a "Strobe" Light

1 Set up the rotor as shown below (Figure 3.1). Leave at least a 30 x 30-cm area of empty tabletop in front of the rotor. Position the cup stands so that the rotor easily rotates or spins, but does not move sideways by more than a centimeter. When you have properly placed the rotor and stands, tape the cup stands to the tabletop.

2 Adjust the position of the washer on the flopper so the flopper tips up slightly on the magnet end (Figure 3.2).

Figure 3.1



3 Rotate the rotor and hold it so one of its magnets is as close to the table as possible (directly under the middle of the rotor). Slide the magnet end of the flopper under the rotor so the magnet of the flopper is directly under the lowest rotor magnet. The rotor magnet and the flopper magnet should repel one another and the magnet end of the flopper should tip down. The objective is to get the magnet end of the flopper to tip down when a rotor magnet is at the lowest point and to tip up after a rotor magnet moves by the lowest point. It may be necessary to bend the paper clip holding the flopper magnet in order to move the flopper magnet closer to the rotor magnet. After making adjustments, tape both sides of the fulcrum to the table. Make a final test by rotating the rotor. The magnet end of the flopper should move down when a rotor magnet comes close to it and then should move back up after a rotor magnet goes by (Figure 3.3).

Materials ...cont'd.

For Part 2—
the electric motor

- *one electromagnet on its cup stand*
- *all the above materials except one 15 cm wire and the bulb and its socket*
- *additional materials as listed in the Teacher's Guide, pages 38–39*

Figure 3.2

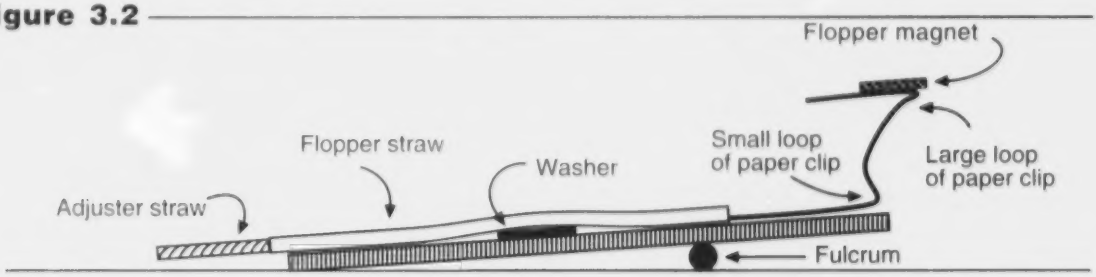


Figure 3.3

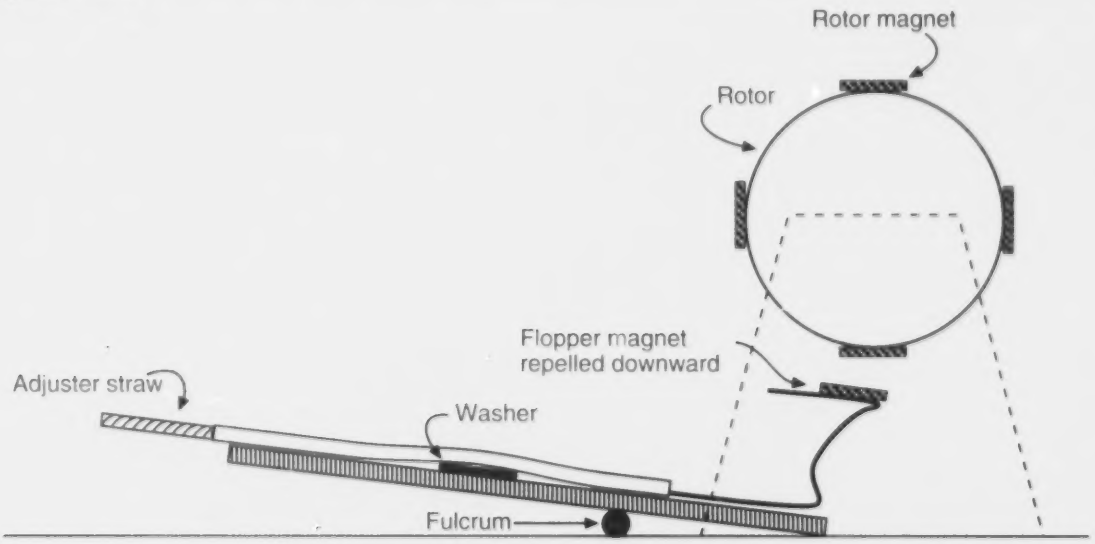
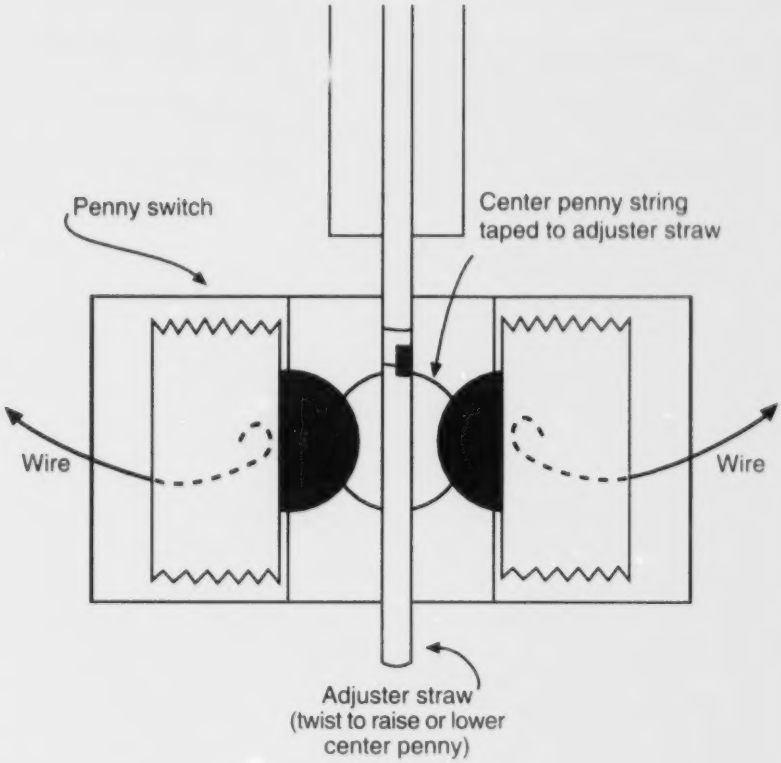


Figure 3.4

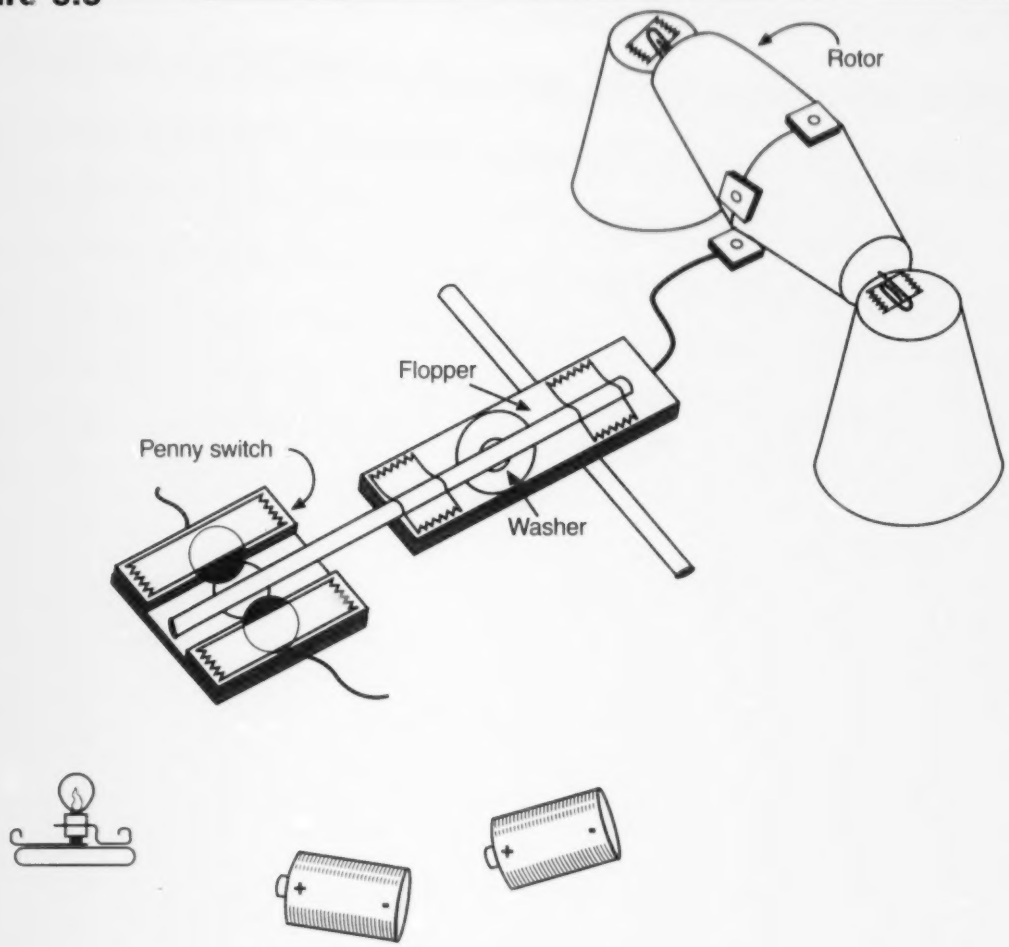


4 Move the penny switch under the back portion of the flopper as shown in Figure 3.4. One edge of the adjuster straw should be midway between the side pennies of the penny switch. Make sure the shiny side of the middle penny is facing up. Use a very small piece of tape to tape the string of the middle penny to the middle of the adjuster straw. Make sure there is at least 3–4 cm of string between the middle penny and the straw. Twist the adjuster straw to shorten or lengthen the penny string. When everything is in place, tape both sides of the penny switch to the table.

5 **Challenge**: Your set-up should look something like Figure 3.5. Create a circuit so that the light bulb blinks on and off as the rotor is turned. Do not remove the wires from the penny switch. Try not to move the flopper. Use the adjuster straw to raise and lower the middle penny of the penny switch. Draw "wires" on Figure 3.5 to show how you connected the various parts to create the "strobe" light.

6 When the rotor magnet is directly over the flopper magnet, what does the flopper magnet do? What does the switch end of the flopper do? Write your answers here.

Figure 3.5



7 When a rotor magnet is directly over the flopper magnet, what happens to the middle penny of the penny switch? Write your answers here.

8 When a rotor magnet is directly over the flopper magnet, is the penny switch on (conducting electricity through it) or is the penny switch off?

9 When there is *no* rotor magnet directly over the flopper magnet, describe what happens to the flopper magnet and describe what happens to the switch end of the flopper.

10 When *no* rotor magnet is directly over the flopper magnet, describe what the flopper is doing to the middle penny of the penny switch.

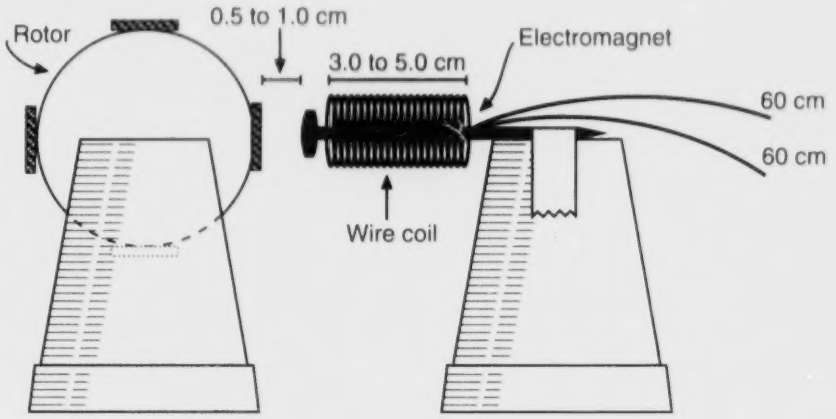
11 When *no* rotor magnet is directly over the flopper magnet, is the penny switch on (conducting electricity through it) or is the penny switch off?

Part 2— Building an Electric Motor

12 Put away the bulb and its socket. Place the electromagnet so that it is as close as possible to the rotor magnets but does not touch any of the rotor magnets as they pass by (Figure 3.6). Thoroughly tape the electromagnet cup to the table. Any movement of the cup and electromagnet will reduce the operation of the motor.

13 **Challenge:** Arrange the batteries and wires so that when the rotor is gently spun, the rotor keeps spinning due to the interaction of the rotor magnets and the electromagnet. Arrange your set-up so that the electromagnet repels each of the rotor magnets. Draw "wires" on Figure 3.7 to show how you connected the objects to get the motor to work.

Figure 3.6

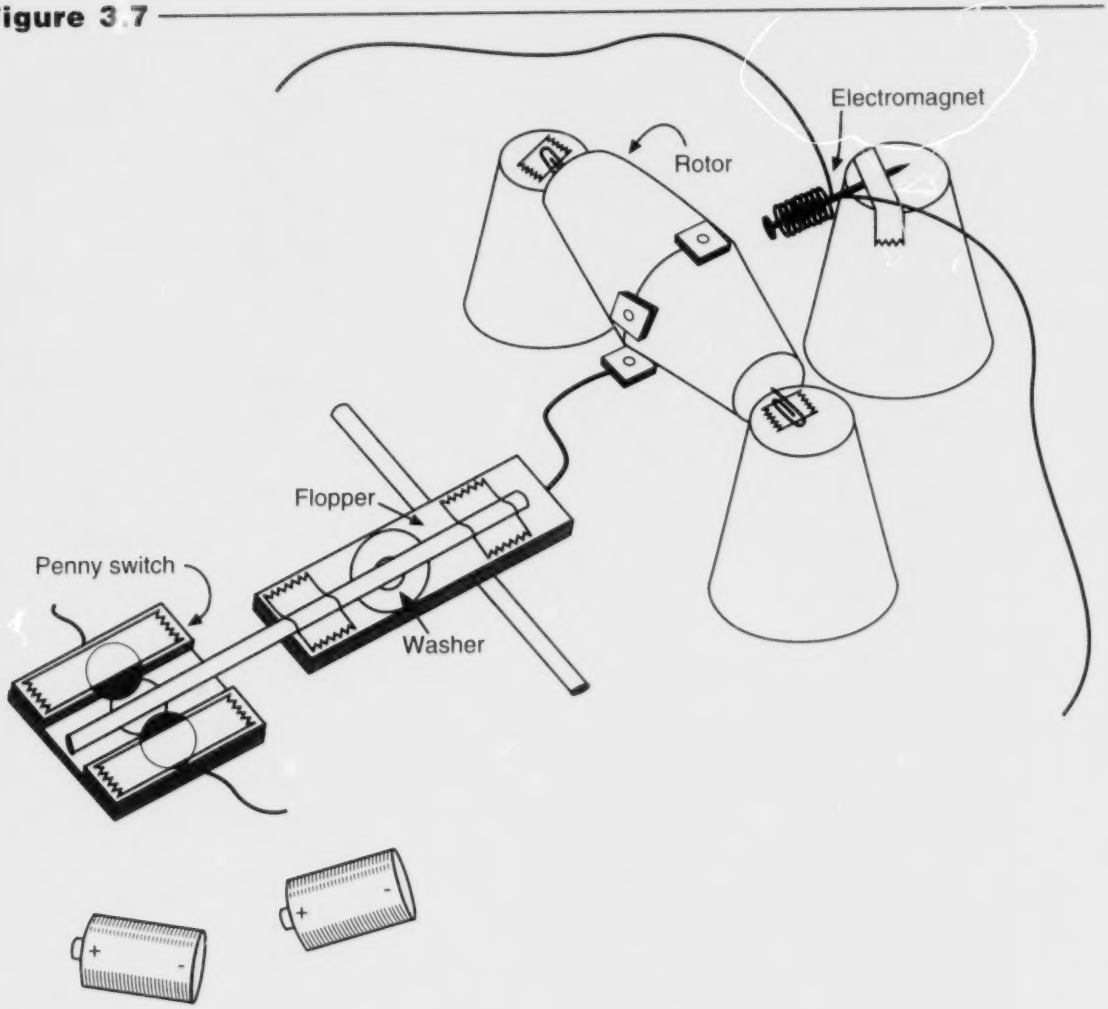


Some notes and hints:

- The electromagnet should repel the rotor magnets. If this does not occur, change the direction of the current through the electromagnet by turning the batteries around or by switching the electromagnet wires in the circuit.
- Adjust the position of the washer on the flopper. You might try to get the motor to work without the washer.
- Try spinning the rotor in different directions. One direction may work better than the other direction.
- Try spinning the rotor slowly or giving the rotor a gentle, but fast spin.
- Twist the adjuster straw to raise and lower the middle penny of the penny switch.
- All electrical contacts must be good. You may have to use sandpaper to clean the contact points. Make sure the enamel has been removed from the ends of all wires.
- Make sure your batteries are fresh. Do not leave a closed circuit on for very long. A closed circuit through an electromagnet will quickly wear out the batteries.

14 Consider what is happening when a rotor magnet is directly over the flopper magnet. When this occurs, another rotor magnet is very close to (almost directly in front of) the electromagnet. The penny switch should be on and electricity should be flowing through the electromagnet. Recall that the current-carrying electromagnet and the rotor magnets have the same poles facing each other. In this position, describe below what the electromagnet is doing to the rotor magnet near it.

Figure 3.7



15 Now consider what is happening when there is *no* rotor magnet directly over the flopper magnet. In this case, the electromagnet is in-between two rotor magnets. One rotor magnet is moving away from the electromagnet and one is moving toward the electromagnet. Now the penny switch should be off and no electricity should be going through the electromagnet. Explain below why it is a good idea to have the electromagnet turned off as a rotor magnet moves toward the electromagnet.

How Real Electric Motors Work

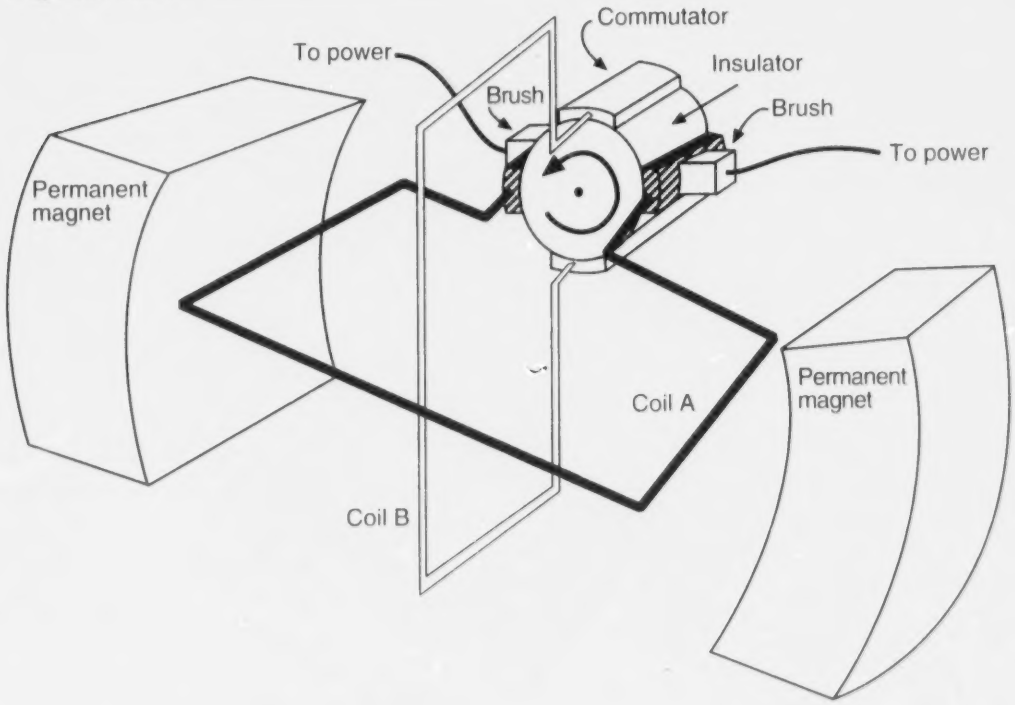
Small electric motors, like the motor made in this activity, turn because of the magnetic interaction between electromagnets and permanent magnets. Usually there are a number of coils or electromagnets in the motor. To maximize turning, these electromagnets must turn on at precise moments.

In larger motors there are no permanent magnets. The motors operate due to the magnetic interaction between electromagnets. Again, timing is everything. The electromagnets must turn on or change their polarity at precise moments to maximize the turning.

Small motors use a number of electromagnets rather than just one. In addition, real motors use a commutator and brushes, instead of floppers and penny switches, to turn the electromagnets on and off. The commutator rotates with the coils. The brushes remain stationary and conduct electricity from the power supply to the commutator. The commutator then conducts the electricity to just one of the coils at a time. The commutator is insulated so electricity is not conducted from coil to coil.

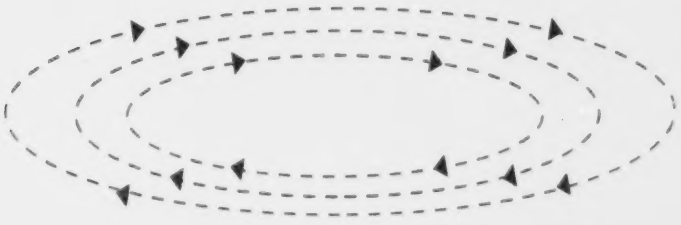
In Figure 3.8, notice that coil A is receiving electricity from the brushes through the commutator. Coil B is not in contact with the brushes and is not receiving electricity. With current flowing through coil A, a magnetic field is created around coil A. This magnetic field interacts with the magnetic field of the permanent magnets and rotates all the coils and the commutator. As the coils and commutator rotate, the brushes lose contact (through the commutator) with coil A and make contact with coil B. Coil B then turns on and coil A turns off. The drawing shows just one loop in each coil. Real coils have many loops wrapped around iron cores and can create very strong magnetic fields.

Figure 3.8


Commutator
To power
Insulator
Brush
Brush
To power
Permanent magnet
Coil A
Permanent magnet
Coil B

Teacher's Guide To

Activity 3



Making an Electric Motor—Electromagnetism in Action

What is happening?

In this activity, students build an electric motor from common objects. In doing so, they see how the magnetic interaction between a permanent magnet and electromagnet produces the rotation of the rotor (see Figure 3.19). They also see how a flopper and penny switch maintain rotation of the rotor by turning the electromagnet on and off at the right moments.

The direction of the current through the electromagnet is chosen so the electromagnet repels the permanent magnets on the rotor. The repelling force turns the rotor. The electromagnet turns off as a permanent magnet rotates toward it. This allows the permanent magnet to approach the electromagnet without being repelled by the electromagnet. Then, just as a permanent magnet moves in front of the electromagnet, the electromagnet turns on and repels the permanent magnet to push it around. The flopper and penny switch work to turn the electromagnet on and off at the appropriate times. **Students will have to troubleshoot and make various changes to get the motor to work. Trial and error, persistence, and creative problem solving will lead to success!** Once students understand the motor in this activity, they are better prepared to understand the presentation of how real motors work. The experience is not unlike what scientists and engineers go through as they create or improve devices. It takes much effort, testing, and sound thinking to produce a device that works reliably.

Materials

For the construction of one motor:

- *five 1-inch-long ceramic, rectangular magnets (available from Radio Shack® Cat. # 64-1879); not always in stock—purchase well in advance*
- *five 16-oz plastic drinking cups*
- *three new pennies*
- *three plastic drinking straws*
- *one 5-m piece of #24 enamel-coated magnet wire (with sanded ends)*
- *two 60-cm pieces of #24 enamel-coated magnet wire (with sanded ends)*
- *two 15-cm pieces of wire with stripped ends*
- *one large, iron nail (approximately 8–10 cm long)*
- *four 1.5-volt dry cells ("C" or "D" size)*
- *two battery holders*
- *three large paper clips (giant or jumbo clips measuring about 1 cm x 4.8 cm)*

Time management

At least two class periods of 40–60 minutes will be required to complete this activity and discuss the results.

Preparation

The first time this activity is used, significant preparation is required. However, since the batteries are the only consumable items, you can save your motors for use with future classes.

There should be one motor for each group of three to four students (eight to ten motors per class of students). **Before constructing all of the materials for class use, you should build a working model for yourself so you are familiar with the construction and operation of the motor.**

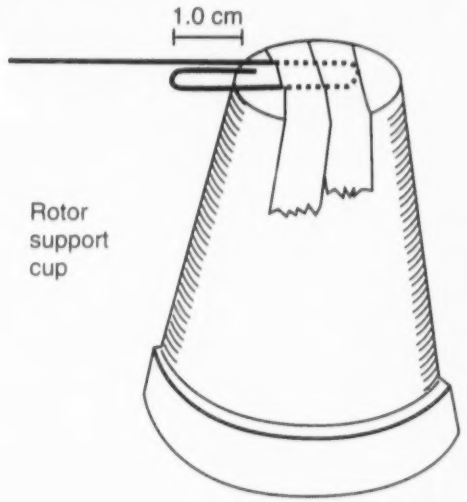
There are a number of different approaches to constructing the parts of the motor. You can (a) construct all the parts yourself; (b) enlist a few careful students to help you with the construction; or (c) guide groups of students in the step-by-step construction of most of the parts.

Making the Rotor and Rotor Stands

a To make stands for the rotor, open and straighten the large loops of two large paper clips. Tape these clips to the bottoms of two cups (Figure 3.9). Make sure there is about 1 cm of the small loop that extends beyond the bottom of the cup. The end of the small loop will prevent the rotor from rubbing against the stand.

b Glue two cups together to make the rotor that will rotate on the

Figure 3.9



paper clips of the stands. Melt a small hole into the bottom of each of these rotor cups. Open up one loop of a large paper clip. Use pliers to hold the end of the paper clip in a flame. Use the hot end of the paper clip to melt a small hole in the bottom of each cup. The hole should be centered, small, and smooth so the rotor rotates freely and evenly.

c To indicate where to place the permanent magnets on the rotor, draw a square with sides equal to the diameter of the cup. Draw diagonal lines from corner to corner in the square. Place the cup upside down inside the square and mark the rim where the lines cross the rim.

d Use silicon glue to glue the rim of the marked rotor cup to the rim of the other rotor cup. Make sure you can see the marks when the two cups are glued together.

e After the glue on the rotor cups is dry, tape (or glue) the four rectangular magnets to the rims of the cups at the marked positions. Make sure that the same pole (north or south) faces outward on all four magnets. In other words, the outward facing side of each magnet should repel the outward facing side of all the other magnets. Make sure that your last piece of tape is *along* the rims, not across the rims. This reduces the chance of a snag when you move the electromagnet close to the rotor magnets.

Making the Electromagnet

About 60 cm from one end of the 5-m length of #24 magnet wire, start wrapping most of the wire around the 3-cm section of nail near the head of the nail. Do not wrap the last 60 cm of wire. Twist the two 60-cm lengths of wire together to keep them from unraveling from the coil. Tape the nail to the bottom of a cup. Sand the enamel off the last 3 cm of each wire. When the electromagnet is used, you will have to tape the cup with the electromagnet securely to the tabletop so that the head of the nail is about 1 cm from a magnet on the rotor.

Making the Penny Switch

The penny switch consists of three pennies. Two of the pennies are separated from each other and are attached to wires in the circuit. In between these two side pennies is the third, middle penny. When this middle penny is lifted and touches the two side pennies, the switch is closed and a current can pass along the chain of pennies.

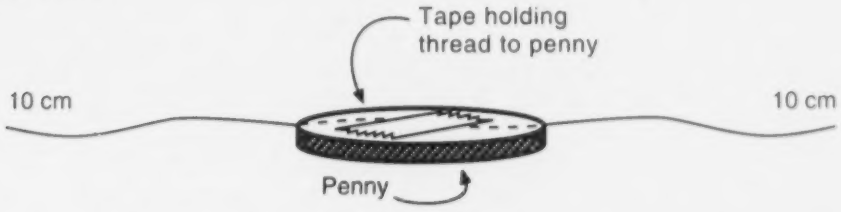
a The pennies must be clean and shiny. To clean and shine the pennies, put the pennies in a container and add enough vinegar to cover them. Rub salt over the pennies in this vinegar bath. The objective is to remove nearly all of the tarnish from the pennies. Sand both sides of all the pennies.

b Use masking tape to attach the middle of a 20-cm piece of thread

Materials ...cont'd.

- *masking tape*
- *one 4 cm x 8.5 cm-piece of cardboard from one tablet-back*
- *one 18 cm x 2.5 cm- and two 3 cm x 4 cm-pieces of corrugated cardboard*
- *one 4 cm x 6 cm-piece of medium or fine grit sandpaper*
- *one tube of silicon glue*
- *one light bulb (#48 or 1.5–3 volt) in its socket*
- *vinegar and salt (to clean the pennies)*
- *one 3 cm x 0.2 cm-iron washer*
- *one 20-cm piece of sewing thread*
- *utility knife*
- *scissors*
- *stapler*
- *pliers*
- *heat source*

Figure 3.10



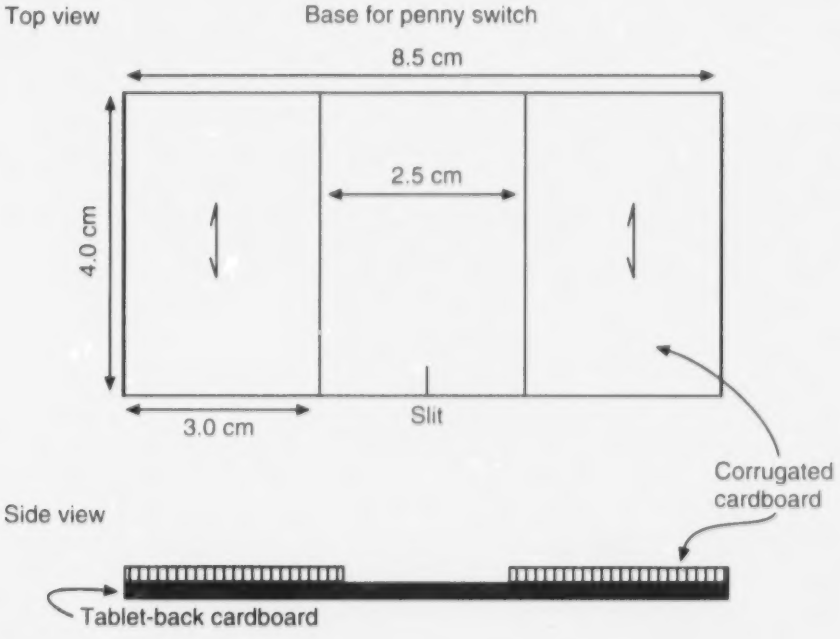
to one side of the middle penny (Figure 3.10). Trim off any excess tape.

c Staple the two 3 cm x 4 cm-pieces of corrugated cardboard to the 4 cm x 8.5-cm piece of tablet-back cardboard as shown below (Figure 3.11). Make sure there is 2.5 cm of space between the two small rectangles. Cut a short slit in the middle of one long side of the base.

d Sand the enamel from the ends of two 60-cm lengths of #24 magnet wire. Make sure there is no enamel left on the last 3 cm of wire.

e Use masking tape to tape the wires to the two side pennies and to the cardboard as shown in Figure 3.12. The side pennies should be 0.5 cm apart. Press the masking tape tightly to the wires and pennies to ensure solid contact between the wires and pennies.

Figure 3.11



f Insert the middle penny beneath the two side pennies. The middle penny should have its shiny side facing up and its taped side facing down. Insert the string into the slit and adjust the string until the middle penny is in about the position shown in Figure 3.13. The string in the slit keeps the penny in place. The other end of the string will be taped to the adjuster straw of the flopper (Figure 3.13).

Figure 3.12

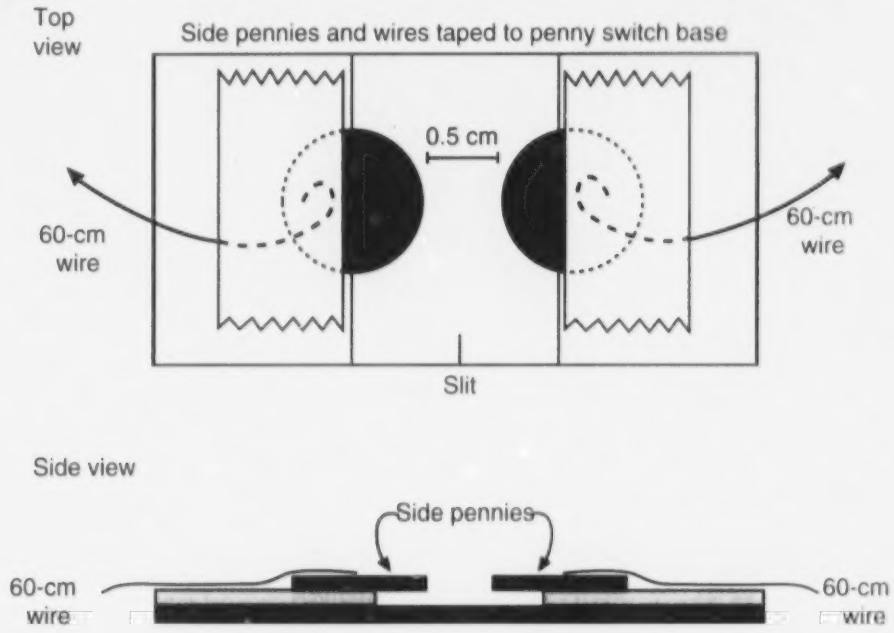
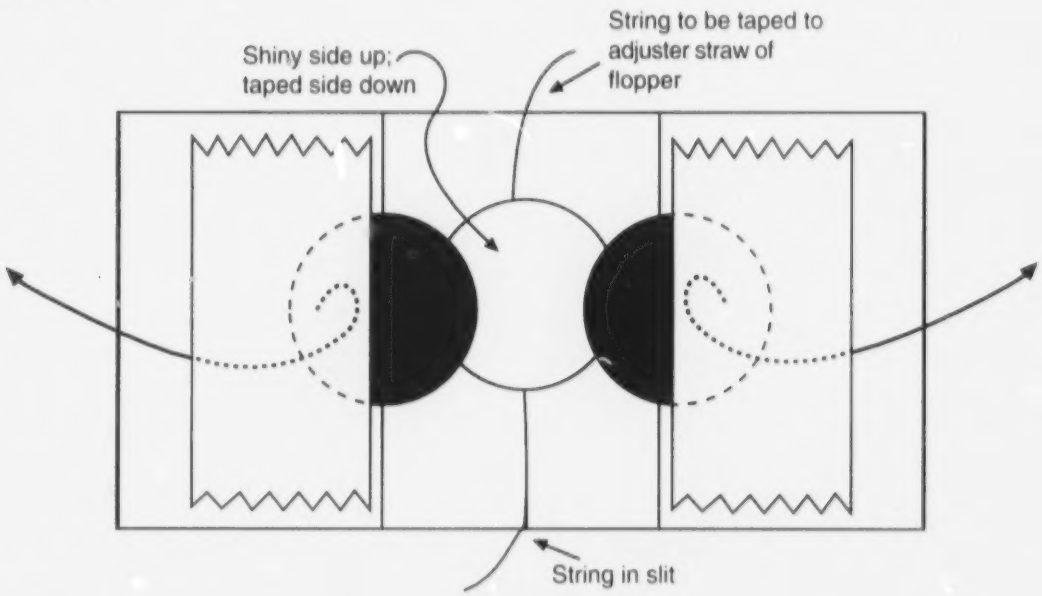


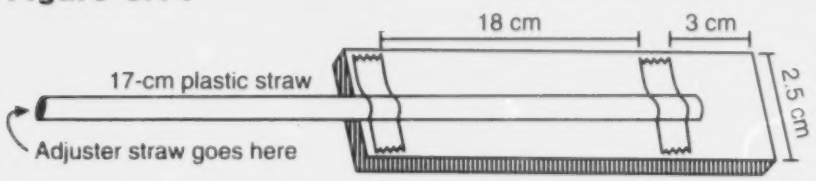
Figure 3.13



Making the Flopper

a Tape a 17-cm section of plastic drinking straw (flopper straw) to an 18 cm x 2.5-cm piece of corrugated cardboard as shown in Figure 3.14. Start the straw 3 cm from one end of the cardboard.

Figure 3.14

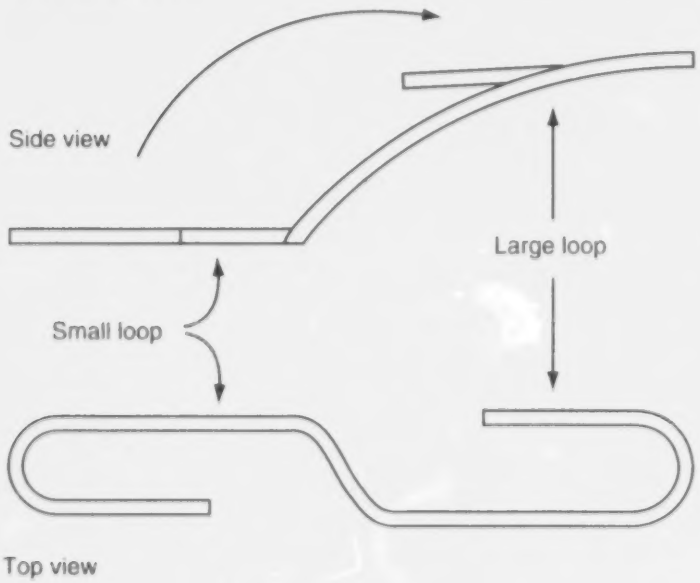


b Cut an 8-cm length of plastic drinking straw (adjuster straw), crimp the one end, and insert the crimped end about 1–2 cm into the extended end of the flopper straw. The adjuster straw should fit snugly inside the flopper straw, but should be able to turn inside the flopper straw.

c Bend open the large loop of a large paper clip as shown in Figure 3.15.

d Tape the small loop end of the paper clip to the end of the flopper as shown in Figure 3.16.

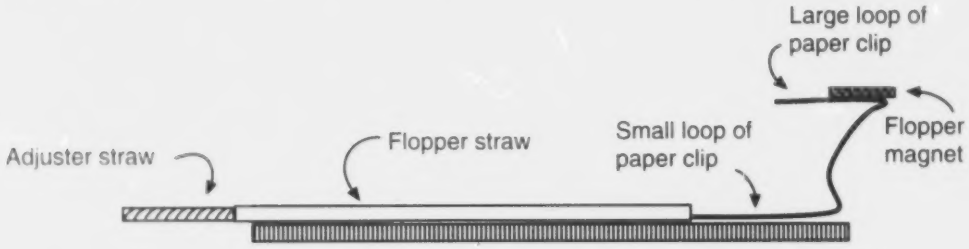
Figure 3.15



e Insert a rectangular magnet in the large loop of the paper clip. Make sure that the side facing upward repels the magnets on the rotor. **It is important to have the flopper magnet and each of the rotor magnets repel one another.**

f Place the washer under the flopper straw about midway between the edges of the tape holding the straw to the cardboard. Move the 12-cm section of plastic drinking straw (fulcrum) under the flopper until the flopper just about balances. Tape the fulcrum to the underside of the flopper. Move the washer forward or backward along the flopper to make adjustments.

Figure 3.16



Reminders and Trouble Shooting

When you introduce the activities, draw students' attention to the drawings and materials, and go over the names of objects (rotor, flopper, magnet end of the flopper, penny switch, etc.). This should help them better understand the challenges and questions.

It is unlikely that all students will construct a motor that works perfectly. Therefore, you will have to be prepared to encourage persistence in troubleshooting and problem solving. Some potential problems (and solutions) follow:

- dry cells may be weak (add more cells in series)
- the batteries may not be connected in series (+ end of one connected to the – end of the other)
- the washer may be too far forward or too far back
- the adjuster straw may have to be turned one way or the other to raise or lower the middle penny of the penny switch
- the electromagnet may not be repelling the rotor magnets (change the direction of current through the electromagnet)
- the wires attached to the side pennies of the penny switch may not be making good contact with the pennies (disassemble, sand, and replace)
- the rotor magnets may not all repel the flopper magnet (flip over one or more magnets)
- the electromagnet may be moving when it interacts with the rotor magnets (securely tape down the electromagnet and the support cup of the electromagnet)

Remind students not to leave their motors on for very long. Even if the motor is not running, current could still be running through the electromagnet, wearing out the dry cells.

The same motor may run in different ways. When the washer is on the flopper, the motor will often run slowly. Each passing rotor magnet pushes the flopper down and turns

on the electromagnet. When a rotor magnet moves past the flopper magnet, the flopper magnet moves upward and opens the switch at the other end. When you remove the washer from the flopper, the motor often runs relatively fast. In this case, the flopper is just rapidly jiggling up and down and is not flopping. The on-off switching, however, is somehow still synchronized with the rotor rotation, but how?

In this high-speed case, without the washer, you would think that the electromagnet would always be on. Even when there is no rotor magnet close to the flopper magnet, the weight of the flopper magnet (not counterbalanced by the washer) should keep the magnet end down and the switch on. Then, when a rotor magnet passes by, the flopper magnet should be pushed further down, keeping the electromagnet on. Since this is not likely the case, something else must be occurring.

One possible explanation is that the flopper magnet might be rebounding upward after being pushed down by a rotor magnet and held in place by the middle penny string. This upward rebound of the flopper magnet might be enough to tip down the middle penny, break the circuit in the penny switch, and turn off the electromagnet.

Suggestions for further study

You may want to challenge students to make changes that make their motors run faster (or slower). You may also challenge them to create a reliable switch that can replace the flopper and penny switch. Some electronics stores have reed switches for sale. The "reeds" in these switches are conductors that come together in the presence of a magnetic field and close the circuit. A reed switch might be an effective substitute for the flopper and penny switch.

Once the motor has operated successfully, students may want to see what happens when there are changes in the number of coils in the electromagnet, the number of batteries in series, the distance between the electromagnet and rotor magnets, and the position of the rotor magnets.

Some students may want to place both the electromagnet and the bulb in the circuit so the motor runs and the light blinks. However, the resistance of the bulb usually reduces the current in the circuit to the point where the strength of the electromagnet is not great enough to run the motor.

Students may want to find some real motors that no longer work, carefully open them, and observe the commutator, coils, and brushes. **Caution students not to attach power sources to these dismantled motors. Serious injury may occur.**

Students may also want to build a very simple electric motor (Figure 3.17):

a Tape a "D" battery to the bottom of a cup.

b Place the magnet, with poles on the large faces, on the side of the battery.

c Bend two large paper clips as shown in Figure 3.17. Hold the paper clips to the battery with a rubber band or with masking tape.

d Wrap a meter of 24-gauge enamel-coated magnet wire around a toilet paper tube to create the coil. Make sure there is enough wire at the ends to wrap around the coil to hold the coil together and to extend out from the coil about 5 cm.

e Sand the enamel off the 5-cm ends of the coil.

f Bend and move the end coil wires so they are in line with the axis of the coil.

g Place the coil in the paper clip cradle and gently spin the coil.

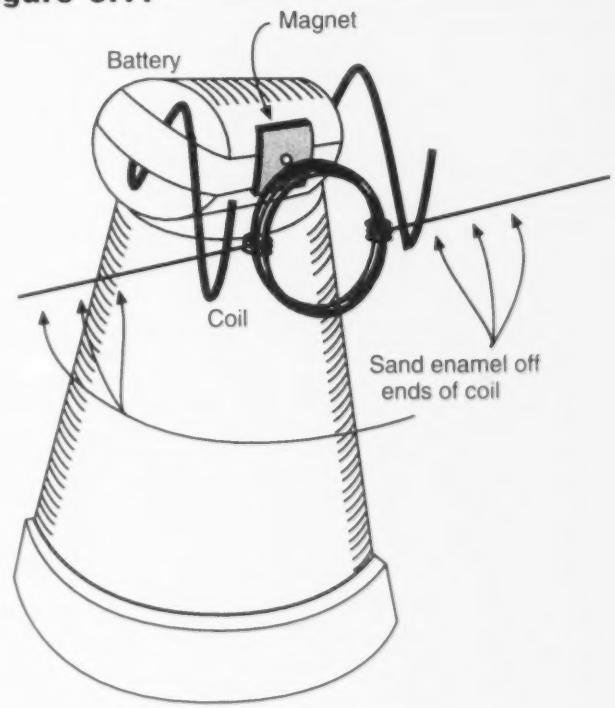
h Bend the paper clips and move the magnet to adjust the relative position of the coil and magnet.

i Press the paper clips to the terminals of the battery.

j With some trial and error adjustments, the coil should begin spinning. The coil spins as its magnetic field interacts with the magnet field of the permanent magnet. The momentum of the coil carries the coil through those regions where the magnetic interaction resists the motion of the coil.

k Since a short circuit is created, the coil and cradle wires could get hot. Remove the coil from the cradle if the coil and wires start heating up.

Figure 3.17



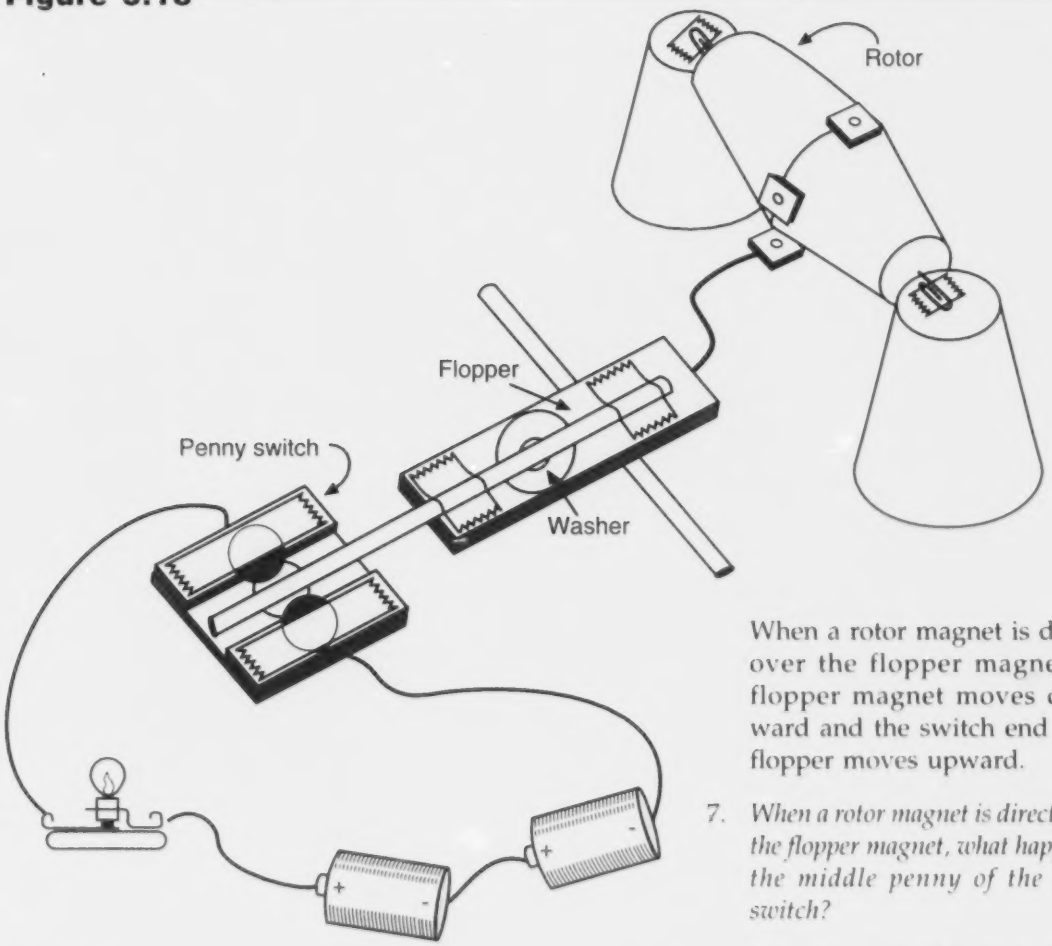
Answers *to questions found within the Student Worksheet on pages 30–35.*

5. *Draw "wires" on Figure 3.5 to show how you connected the various parts to create the "strobe" light.*

   The correct connections for the "strobe" light are shown in Figure 3.18.

6. *When the rotor magnet is directly over the flopper magnet, what does the flopper magnet do? What does the switch end of the flopper do?*

Figure 3.18



When a rotor magnet is directly over the flopper magnet, the flopper magnet moves downward and the switch end of the flopper moves upward.

7. *When a rotor magnet is directly over the flopper magnet, what happens to the middle penny of the penny switch?*

When a rotor magnet is directly over the flopper magnet, the switch end of the flopper pulls the middle penny upward.

8. *When a rotor magnet is directly over the flopper magnet, is the penny switch on (conducting electricity through it) or is the penny switch off?*

When the switch end of the flopper pulls the middle penny upward, the middle penny

touches the two side pennies, closes the penny switch, and allows electricity to flow through the switch. The penny switch is on.

9. *When there is no rotor magnet directly over the flopper magnet, describe the movement of the flopper magnet and describe the movement of the switch end of the flopper.*

   When no rotor magnet is directly over the flopper magnet, the flopper magnet moves upward while the switch end of the flopper moves downward.

10. *When no rotor magnet is directly over the flopper magnet, describe what the flopper is doing to the middle penny of the penny switch.*

    When no rotor magnet is directly over the flopper magnet, the switch end of the flopper moves downward and allows the middle penny to move downward away from the side pennies.

11. *When no rotor magnet is directly over the flopper magnet, is the penny switch on (conducting electricity through it) or is the penny switch off?*

    When the switch end of the flopper moves downward and allows the middle penny to move downward away from the side pennies, the middle penny breaks contact with the side pennies and opens the penny switch so no electricity flows through it. The penny switch is off.

13. *Draw "wires" on Figure 3.7 to show how you connected the objects to get the motor to work.*

    The correct connections for the motor are shown in Figure 3.19.

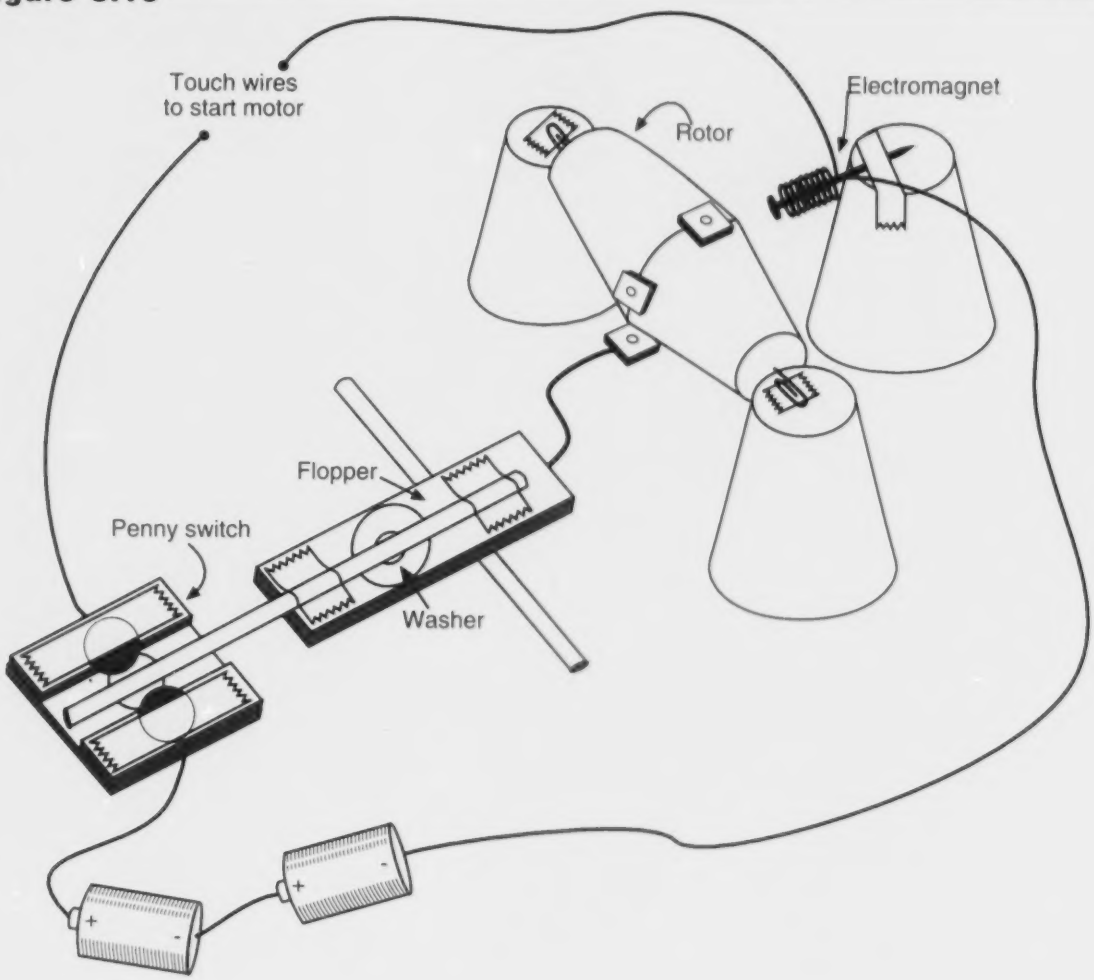
14. *When a rotor magnet is directly over the flopper magnet, another rotor magnet is almost directly in front of the electromagnet. With the penny switch on and electricity flowing through the electromagnet, describe what the electromagnet is doing to the rotor magnet near it.*

    With the penny switch on, electricity should be moving through the electromagnet and the electromagnet should be magnetized. Since the electromagnet and the rotor magnet are arranged to repel one another, the electromagnet should be repelling the rotor magnet that is directly in front of it. The repelling force rotates the rotor.

15. *In a case where the electromagnet is in-between two rotor magnets, one rotor magnet is moving away from the electromagnet and one is moving toward the electromagnet. Explain why it is a good idea to have the electromagnet turned off as a rotor magnet moves toward the electromagnet.*

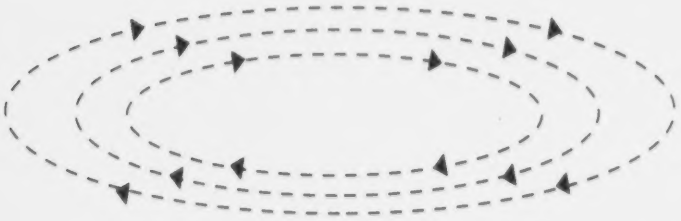
    Knowing that the electromagnet (when on) and rotor magnets repel one another, it is a good idea to turn off the electromagnet so that an approaching rotor magnet is not repelled by the electromagnet.

Figure 3.19


Touch wires
to start motor
Rotor
Electromagnet
Flopper
Penny switch
Washer
+
-
+
-

Activity 4

Student Worksheet



Motion, Magnetism, and the Production of Electricity

Background

When Hans Christian Oersted discovered that a current-carrying conductor produces magnetism, the opposite process surely came into question: Can magnetism produce electricity? Oersted and others tried to produce electricity from magnetism, but it wasn't until 1832—twelve years after Oersted's discovery—that Michael Faraday, an English physicist, and Joseph Henry, an American physicist, independently and simultaneously produced electricity from magnetism. Faraday gets the credit because he was first to publish his discovery. What Oersted and others missed, but what Faraday and Henry discovered, was that in order to produce electricity from magnetism, it is necessary to move the magnet or the wire. In this activity, you will observe how motion and magnetism can produce electricity and in the process you will be building a generator.

Concept Goals

- A generator can be built from available simple materials (magnets, wire, etc.).
- If a closed circuit coil is moved in a magnetic field, an electrical current is produced in the coil and circuit.
- Motion and magnetism create the electricity that we use in our homes, schools, and businesses.

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Topic: generators
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Materials

For each group:

- *one 3-m piece of 24-gauge enamel-coated wire (for the rotating coil)*
- *two 40-cm pieces of 24-gauge enamel-coated wire (sand the enamel from 4-cm sections at the end of the wires)*
- *two pieces of 20-gauge copper wire, each about 20 cm long*
- *two strong ceramic or rubberized magnets with the poles on the larger surfaces or faces. The magnets can be circular or rectangular and should measure about 1.6 cm to 2.5 cm across and about 0.3 cm thick.*
- *masking tape*
- *wire cutters*
- *one 7-cm x 11.5-cm piece of medium or fine grit sandpaper (used to sand the enamel from the ends of the wires)*
- *a felt-tipped marker to wrap the coil around (optional)*

- Stronger magnets, more loops in the coil, and a faster spinning coil produce more current.
- Some power plants use fossil fuel or nuclear energy to form steam that turns coils to produce electricity. Other power plants use wind and moving water (streams and rivers) to turn coils to produce electricity.

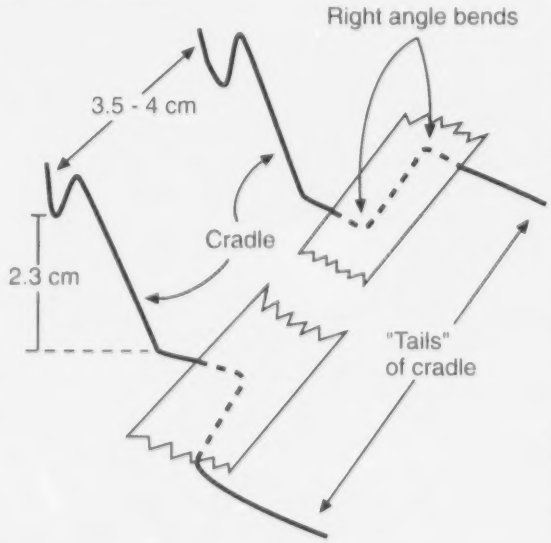
Procedure

1 As noted in the Background section above, electricity can be produced in wires from magnetism and either movement of the wire or movement of the magnet (WIRES + MAGNETISM + MOVEMENT = ELECTRICITY IN THE WIRES). Movement of magnets might cause movement in the needles of the current detectors. Therefore, to make sure that the movement in the needles is caused by electricity and not by moving magnets, it will be better to keep the magnets still and move the wires.

2 One way to make a lot of wire move rapidly in a small space is to create a coil of wire and have that coil spin in a cradle. If a coil has not been provided, make a coil by following the directions at the end of this activity ("How to Make the Rotating Coil," pages 58–60).

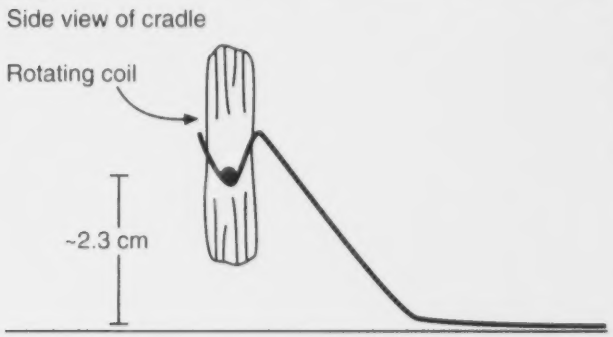
Figure 4.1

Top view of cradle



3 **Making the Cradle for the Rotating Coil** (Figures 4.1 and 4.2). The cradle consists of two copper wires (each 20 cm long) that hold the rotating coil and allow it to spin. At least 5-cm sections of the ends of these wires must be bare copper wire (no plastic insulation or enamel). The cradle conducts any electricity generated by the rotating coil to the current detector (galvanometer or coil and compass). The two pieces of 20-gauge wire (heavy wire) are bent into the shapes

Figure 4.2



as shown in Figures 4.1 and 4.2 and are taped to the table about 3.5 cm to 4 cm apart. The bottom of the cradle loops should be about 2.3 cm off the tabletop. Note in the top view that there are right-angle bends in the wire on the table. The cradle is more secure when the right-angle bends are securely taped to the table.

4 Connecting the Current Detector to the "Tails" of the Cradle. Use the two 40-cm pieces of 24-gauge wire to connect the "tail" of the cradle to the current detector (see Figure 4.3). Make sure that 4-cm sections of the ends of the wires have been sanded to remove the enamel. Also, it might help to sand the "tails" of the cradle as well. Move the current detector at least 20 cm away from the rotating coil and cradle.

If a compass and coil are used as a current detector, rotate the compass and coil on the tabletop until the compass needle lines up with the top of the coil. Since any movement of the compass and coil will make it hard to detect needle movement, tape the compass support to the table. Also, tape down wires leading to the compass and coil.

5 Giving the Coil a Spin. Once the cradle has been connected to the current detector, place the rotating coil in the cradle. Using one of the "tails" of the rotating coil, give the coil a spin. Movement of the needle of the current detector indicates that electricity was produced in the rotating coil. Was there any evidence that the electricity was produced in the rotating coil?

Materials ...cont'd.

- *a current detector (either a galvanometer or a coil and magnetic compass)*

If a galvanometer is not available, the following materials are needed to make a current detector from a coil and magnetic compass (See "How to Make a Current Detector" on page 60):

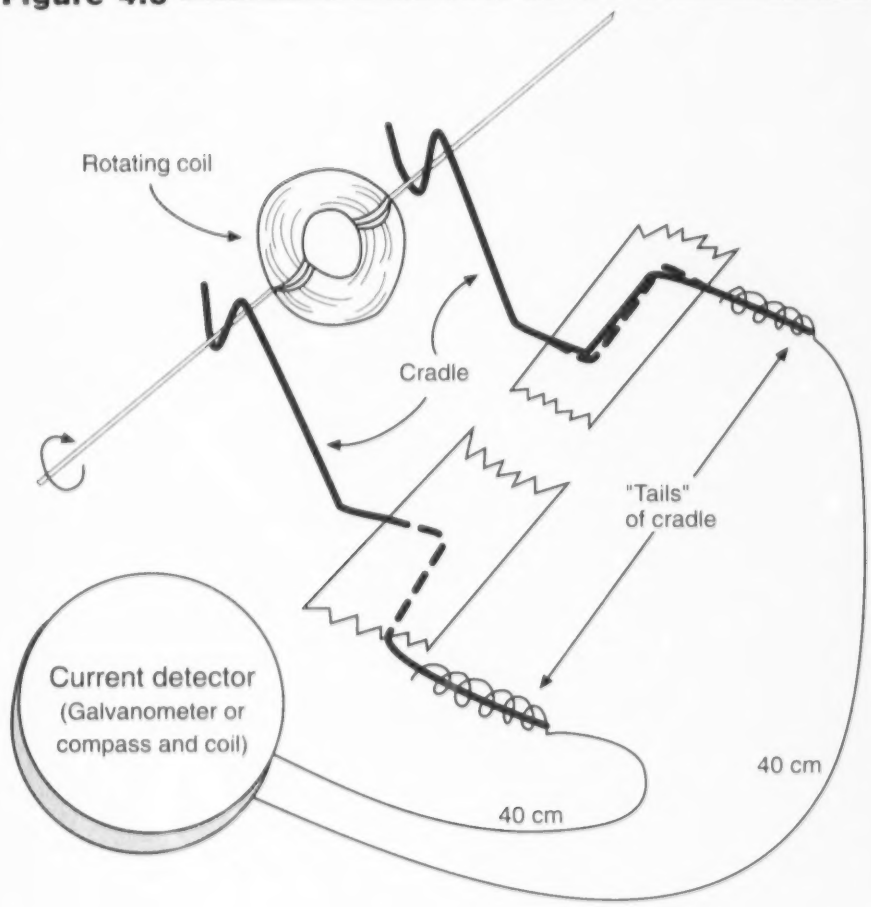
- *one directional, magnetic compass (the compass must not "lock up" or "stick" when the needle is stationary)*
- *one 4.5-m piece of 24-gauge, enamel-coated wire (for the compass coil). Sand the enamel from 4-cm sections at the ends of the wire.*
- *one square piece of cardboard (tablet-back thickness) with sides that are about 1 cm longer than the diameter of the compass body*

Materials ...cont'd.

Optional Materials for Making a Magnet Holder (See "How to Make a Magnet Holder" on page 61):

- *one rectangular piece of cardboard (tablet-back thickness), approximately 1 cm x 8 cm*
- *one giant or jumbo paper clip (approximately 4.8 cm x 1 cm)*
- *one 4-cm section of plastic drinking straw*
- *one "D" battery or beaker. Since the battery is used only to hold a magnet, the battery can be dead.*

Figure 4.3



6 Challenge: Figure out how to use one or both magnets with the rotating coil to produce and detect electricity. Recall that sandwich magnets have poles on the large, flat surfaces (not on the ends). Also, recall that like poles repel and different poles attract. The position of the poles will likely be important in meeting this challenge. One person may want to hold the magnets while another person spins the rotating coil. A third person may want to watch the current detector. Whenever a test is made, make sure that the magnets are not moving.

Describe how you hold the magnets around the rotating coil to produce and detect electricity. The poles are important. Try to discover and describe how the poles should be placed.

7 Once electricity is produced and detected, answer the following questions through experimentation:

a Try spinning the coil in different directions. How is the direction of coil spin related to the direction in which the needle moves?

b Compare needle deflection for slow spinning and fast spinning. How does the rate of spin relate to the extent of needle deflection and consequently to the electrical current in the wire?

c What do you think would happen to the deflection and current if just 1 m of wire, rather than 3 m, was used to make the rotating coil?

d What do you think would happen to the deflection and the current if weaker magnets were used?

8 Faraday's Law. Michael Faraday and Joseph Henry independently discovered that a current could be produced in a closed circuit coil if that coil moved relative to a magnetic field or region of magnetic influence. The coil must move and/or the magnetic field must move such that the coil wires move across the magnetic field, which runs from north pole to south pole. The production of electricity from motion and magnetism is called *electromagnetic induction.*

Faraday was first to get his discovery published so he gets most of the credit for discovering electromagnetic induction. Faraday also had a law named after him, "Faraday's Law of Induction." In terms of this activity, Faraday's law would predict that if the number of loops in the coil is doubled and if the coil spins twice as fast (cuts the magnetic field twice as often), the induced current would be four times as great (assuming the same resistance).

9 The Production of Electricity for the Community. The electricity that is made available to your home and community is produced in a way that is very similar to the way electricity was produced in this activity. In your

community or in a community nearby there is an electrical power plant. In that plant, coils of wire are moved in a magnetic field. As a consequence, an electrical current is produced in the coils and in the wires leading to your home where the electricity is used to run your electrical devices.

In this activity, chemical energy in you was transformed into energy of motion (spinning the coil), which was transformed into electrical and magnetic energy (current in the wires), which was transformed back into energy of motion (movement of current detector needle). In electrical power plants, motion energy (spinning of coils) is transformed into electrical and magnetic energy.

Power plants have different ways of moving the coils. For some (hydroelectric plants) running or falling water from rivers is used to turn the coils. For others, coal or gas (fossil fuel) is burned to produce steam, which turns the coils. For still others, nuclear energy is used to produce steam, which turns the coils. In some cases (windmills), wind is used to turn the coils. It can be said that we get most of our electrical energy from moving air or water (liquid or gas).

How fascinating it is to think that energy from some cold stream miles away is transmitted almost instantly to the warm computer on which this sentence is being typed and stored... and to think that others are dipping into that same stream for the energy used to run their computers, lights, and innumerable gadgets.

Less than two and a half lifetimes ago we did not know how to produce electricity from magnetism. Thanks to Faraday and Henry, not only do we now know how to do that, but we have built on that foundation to create a wondrous collection of electrical systems and devices. Communication around the world used to take months or years. Now, even without connecting wires, we can communicate with minimum delay in words and pictures with nearly anyone in the world. The discovery of electromagnetism and electromagnetic induction has shrunk the human world and stands as one of the most significant advances of the 20th century.

TECHNOLOGICAL TIE-IN

Superconductors

Scientists and engineers are working on improving the way we generate and distribute electricity. Wires in the coils of generators and wires between the power plant and our homes, schools, and businesses all resist the flow of electricity. If we could reduce that resistance so the electricity could move more easily, then we would be able to use less energy to produce electricity and we would be able to reduce pollution that comes from the production of electricity. Scientists and engineers are working on ways of reducing electrical resistance. They have already discovered that some materials at very low temperatures provide no resistance to the flow of electricity. These materials are called superconductors. If we had highways that acted like superconductors, we could get our car up to 60 miles per hour, shut off the engine, and coast at 60 miles per hour for as long as we wanted to. We would not have to use fuel to move down the highway; therefore we would save money and energy and have a cleaner environment. The problem at this point in time is that superconductors have to be kept super cold. Keeping things cold (about 200 Celsius degrees below the freezing point of water) requires the use of energy. Scientists and engineers are currently trying to create superconducting materials that operate at relatively high temperatures. Creating a superconductor that operated at room temperature would revolutionize the electrical world. Scientists and engineers are experimenting with superconducting power lines and with superconducting electrical generators. If the superconducting generators and power lines prove successful, we will probably be able to cut our costs, energy requirements, and pollution to more than half of what they are today.

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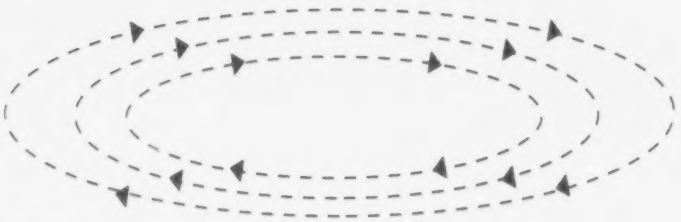
Teacher's Guide To

Activity 4



Motion, Magnetism, and the Production of Electricity

What is happening?

In this activity, students learn how to produce or generate electricity from moving a closed circuit (coil) through a magnetic field. They construct a coil that spins in a cradle. Magnets held close to the spinning coil create a magnetic field (region of magnetic influence) in which the coil spins. The wires of the coil cut across the magnetic field between the two magnets and a current is created in the spinning coil, in the cradle, and in the current detector.

Students observe that the direction in which the coil is spun determines the direction in which the needle of the current detector is deflected and hence the direction the current is moving. They also learn that when the coil is spun faster, there is greater needle deflection, which indicates greater current. In addition, students learn that stronger magnets and more loops in the spinning coil would produce greater current (deflection).

The simple generator made in this activity is related to the generators used by electrical power plants. Basically students learn that power plants move coils in magnetic fields and in the process produce the electricity used in homes and the community. Energy is required to move the coils, whether the coils are on classroom desktops or in power plants. Students learn that fossil fuels and nuclear energy are used to form steam, which turns the power plant coils. Students also learn that wind and moving water (from rivers and dams) are used to turn the coils in the production of household electricity.

Time management

Two class periods of 40–60 minutes each should be enough time to complete the activity and discuss the results. If galvanometers are available, then less time is required since students need not make the current detector from a compass and coil. Also, more time can be saved by having a couple of careful students help after school to make all the rotating coils for the class. Once these coils are made they can be used repeatedly by other classes.

Preparation

To save classroom time, use student help to cut all of the materials prior to class (e.g., wires, sections of drinking straws, and the cardboard for the compass and the magnet holders).

If a compass is being used to detect currents, that compass should be in good working order. Very small currents and their associated magnetic fields will not deflect a compass needle if that needle tends to stick when it is stationary. Check to see that smoothly operating compasses are used in this activity. If a needle does seem to stick, have the student lightly tap the compass to set the needle jiggling. With the needle jiggling, spin the rotating coil and look for evidence of deflection and current.

Also, if compasses are being used to detect currents, warn students to keep magnets and iron objects away from their compasses. A compass needle will be held in place by a nearby iron object or magnet and therefore might not be easily deflected by the weak magnetic field from the coil around the compass.

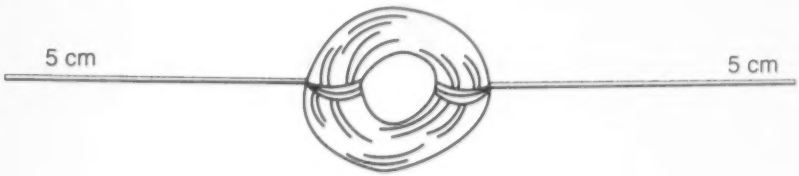
How to Make the Rotating Coil

1. About 15 cm from one end of the 3-m wire, start wrapping the wire around an index finger or a felt-tipped marker. Keep the wire rather snug around the object, but loose enough to get the coil off the object. Leave about 15 cm of unwrapped wire at the end of the wire. Wrap the two 15-cm ends about three times around the coil on opposite sides of the coil. Cut the wires so about 5 cm of wire extend outward on each side of the coil. These wires are the "tails" of the rotating coil (see Figure 4.4).

2. Sand *only the tops* of the 5-cm "tails" (wires) of the rotating coil. To do this, place a piece of cardboard at the edge of the table (see Figure 4.5). Hold the coil in a vertical position on the edge of a table with one "tail" resting on the cardboard. Sand the top of the "tail." Also, sand the top of the other "tail." Make sure the same sides of the wires are sanded. Also, make sure the tops of the wires are sanded near the coil. Do not sand the wire that is in the coil.

3. Straighten and bend the "tails" so they line up through the middle

Figure 4.4



Rotating coil made from wrapping
3 mm of wire around a felt-tipped marker or index finger

Figure 4.5

Side view

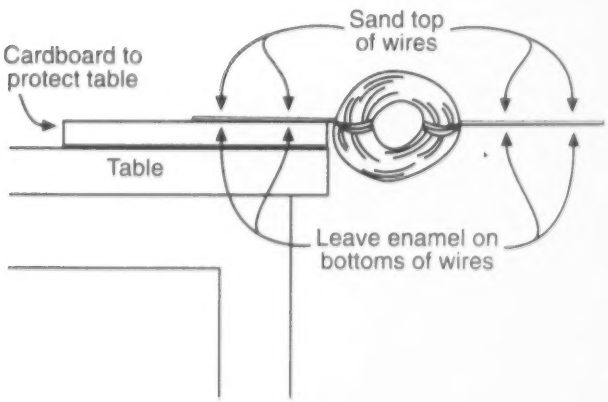


Figure 4.6

Figure 4.7

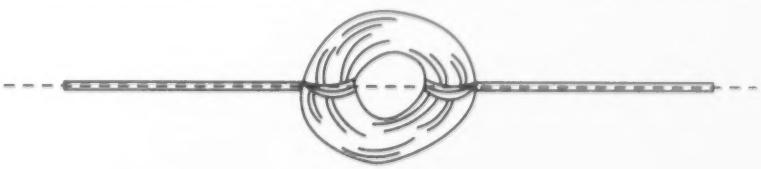


Figure 4.8

Top view

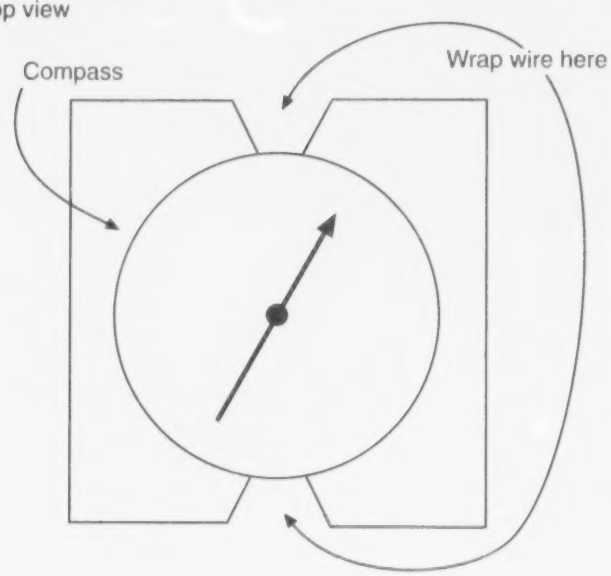
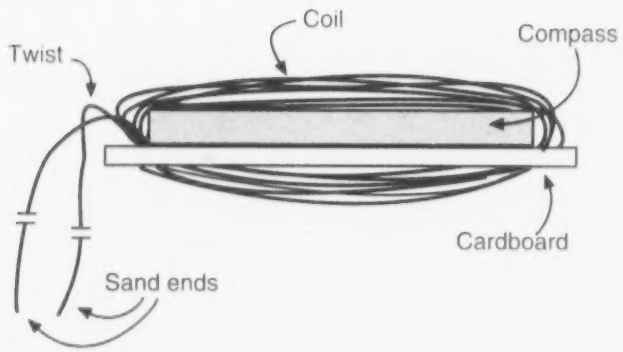


Figure 4.9

Side view



of the coil. Make sure the wires line up from two different views (see Figures 4.6 and 4.7). You will want to bend the wires so the coil is well balanced and does not wobble when it spins in the cradle.

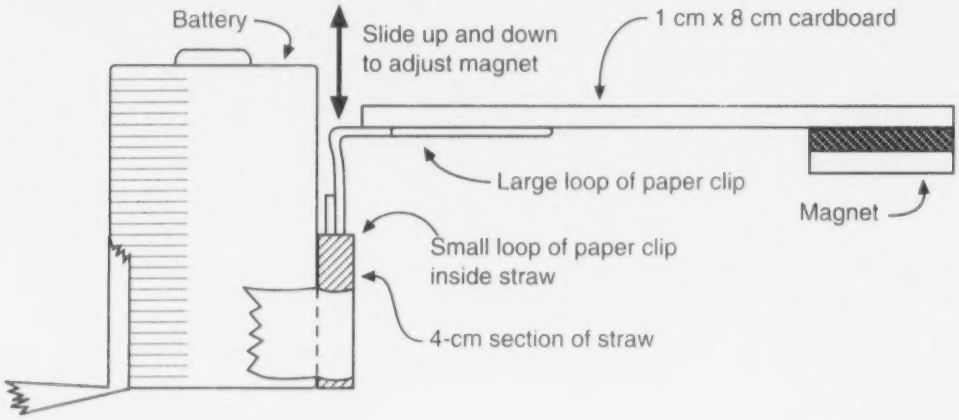
How to Make a Current Detector

1. Cut a square piece of cardboard with sides about 1 cm longer than the outside diameter of the compass. Cut 0.5-cm notches in the middle of two opposite sides of the square. The notches will hold the coil of wire over the middle of the compass.

2. Place the center of the compass over the center of the square. Starting about 12 cm from one end of the 4.5-m piece of wire, wrap the wire around the compass and square and through the notches. Stop wrapping when there is about 12 cm of wire left. Twist the two wires together close to the compass. Sand the enamel off 4-cm sections at the ends of the wires. (See top view in Figure 4.8 and side view in Figure 4.9.)

   If the electrical current flowing through the coil is great enough, the current will produce magnetism strong enough to move the compass needle.

Figure 4.10



How to Make a Magnet Holder

A magnet holder can be used to hold a magnet over the rotating coil (Figure 4.10).

1. Tape a magnet to the end of the 1 cm x 8 cm-piece of cardboard.
2. Tape a 4-cm section of plastic drinking straw to a battery (dead or alive) or beaker.
3. Bend the large loop of a jumbo paper clip so that the large loop is a right angle to the rest of the paper clip.
4. Tape the large loop of the paper clip to the piece of cardboard as shown.
5. Slip the small loop of the paper clip into the straw.
6. Slide the cardboard, clip, and magnet up and down in the straw to adjust the height of the magnet.
7. Set the magnet over the top of the rotating coil.

Question: If this magnet is directly over the rotating coil, where should the other magnet be placed to produce the greatest current in the coil?

Suggestions for further study

Students may be challenged to see how changes in the rotating coil might produce more or less current (deflections). Will a rotating coil made from 1 m of wire produce the same deflection (current) as a rotating coil made from 3 m of wire? Does the gauge of the wire make a difference? What will happen if weaker or stronger magnets are used?

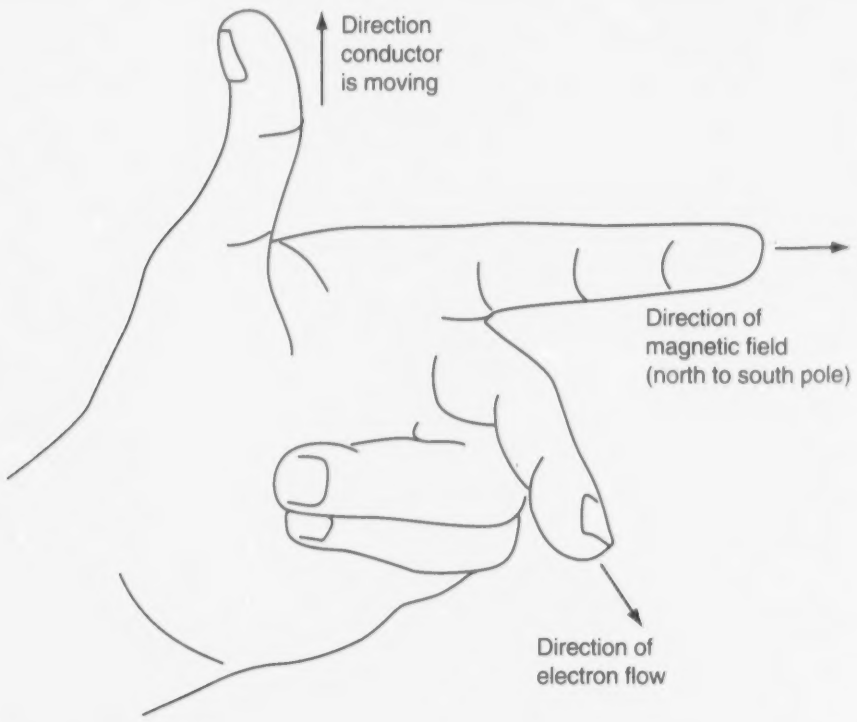
Students may wonder why only half the enamel is removed from both ends of the rotating coil wire. If the enamel is removed from all around

the wire, the coil should produce an alternating current. An alternating current is a current that changes directions back and forth in the conductor. For half a turn of the coil the electricity would travel in one direction and for the other half of a turn the electricity would travel in the opposite direction. Alternating current in the compass coil would produce an alternating magnetic field and the needle would jiggle back and forth after an initial jump in one direction.

To produce an intermittent, direct current, and hence sustained needle deflection in one direction, the enamel is left on half the wire so that no electricity flows to the compass coil during that half of the turn.

How can we tell which way the current should be traveling in a conductor that is moving across a magnetic field? A left-hand rule for generators or electromagnetic induction can be used. To implement the rule, point the thumb and index finger of the left hand perpendicular to one another. Point the thumb in the direction the conductor is moving and point the index finger in the direction of the magnetic field (from north pole to south pole). The middle finger, held perpendicular to both the thumb and index finger, will point in the direction of the electron flow (see Figure 4.11).

Figure 4.11



Interested students may be challenged to use this left-hand rule to determine the direction of electron flow in a coil that is rotating in a magnetic field. It may help to simplify the rotating coil by considering only one or two loops. Students should discover that the current moves in one direction during one half of a spin and moves in the opposite direction during the other half of the spin.

Answers *to questions found within Procedure on pages 51–54.*

5. *Was there any evidence that the electricity was produced in the rotating coil?*

   Here the students spin the coil in the cradle, but without using the magnets. If magnets are not held close to the spinning coil, no electricity will be produced in the coil and no current will be detected.

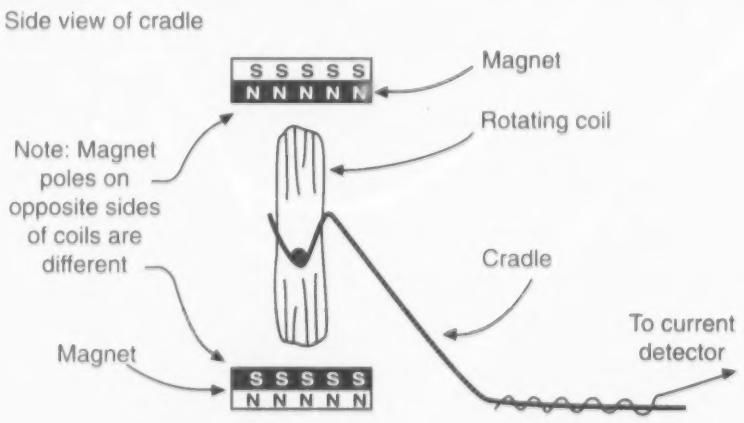
6. *Describe how you hold the magnets around the rotating coil to produce and detect electricity.*

   Students meet this challenge by holding the two magnets motionless in various places about the spinning coil. The challenge can be difficult. Here are a couple of hints to give students if frustration levels run too high.

- Place one magnet directly under the rotating coil. Where would you place the other magnet to produce electricity in the spinning coil?
- Hold the other side (pole) of the magnet close to the spinning coil.
- The magnets need to be on opposite sides of the spinning coil.
- The pole (or side of the magnet) facing the coil might make a difference.

The magnet arrangement that will produce the strongest current will be one in which magnets are held on opposite sides of the coil, with different poles facing each other (see Figure 4.12). For example, if one magnet is placed close to and directly under the coil and the other magnet is held close to and directly over the top

Figure 4.12



of the coil and if the magnets' poles closest to the coil are different (magnets attracting), then electricity should be generated in the spinning coil.

7a. *How is the direction of coil spin related to the direction in which the needle moves?*

When the direction of coil spin is reversed, the needle deflection and current are reversed as well.

7b. *How does the rate of spin relate to the extent of needle deflection and consequently to the electrical current in the wire?*

Faster spin produces greater needle deflection and greater current.

7c. *What would happen to the deflection and current if just 1 m of wire (rather than 3 m) were used?*

A coil made with 1 m of wire would produce less needle deflection and current than a similar coil made from 3 m of wire.

7d. *What do you think would happen to the deflection and current if weaker magnets were used?*

Weaker magnets would produce less needle deflection and current than stronger magnets.

Glossary

Circuit

A circuit is a path of objects along which an electrical current can flow. The circuit usually includes an electrical power source (battery or generator) and wires that run to and from the power source.

Closed Circuit

A closed circuit is a circuit that has an unbroken path of conductors that run to and from the power source. There are no non-conducting sections along a closed circuit path.

Coil

A coil is made when an insulated wire is wrapped a number of times around an object in the same direction. Usually the wraps of wire lie on top of or next to the other wraps of wire. If the object is removed, the wire wraps are still considered to be a coil. When an electrical current passes through the coil, magnetism is created around each wrap. Since many wraps are on top of each other or beside each other, the magnetism from each wrap adds up to produce a strong magnetic effect (attraction) around the coil.

Conductor

A conductor is a material that electricity or an electrical current can easily pass though. Metals are usually good conductors of electricity.

Current

Current is a measure of how "fast" the electricity is moving in a conductor. The speed is not measured in speedometer speed (e.g., 50 miles per hour). It is measured by counting the number of charges (electrons or protons) that pass any point in the conductor in one second. If you sat beside a highway and counted the number of cars that passed you in a second or minute or hour, you would be measuring the "current" of cars (e.g., 35 cars in one hour). The "current" of cars would not be the same as their speed (e.g., 50 miles per hour).

Electrical Resistance

Some materials allow electricity to easily flow through them. Other materials make it difficult for electricity to flow through them. Electrical resistance is a measure of how hard an object resists the flow of electricity through it. Objects with high resistance put up a great resistance to the flow. Objects with low resistance put up little resistance to the flow. For example, the longer and skinnier a wire is, the more resistance it has to the flow of electricity.

Electromagnetic Induction

When a conductor is in a changing magnetic field (region of magnetism), a voltage is produced (induced) in the conductor and that voltage can pro-

duce an electrical current in the conductor. This process is called electromagnetic induction. The electricity that we use in our homes, schools, and businesses is produced by electromagnetic induction. Generators produce electricity by electromagnetic induction. In Activity 4, when the generator coil spins between two magnets, the coil moves though different regions of magnetism. This produces an electrical current in the spinning coil and this current is detected by the galvanometer or the stationary coil and compass.

Electromagnetism

Electromagnetism is the production of magnetism in the space around a wire carrying an electrical current. Also, electromagnetism is the production of magnetism in the space around a moving charged particle.

Electrons

Electrons are negatively charged particles that move around the nucleus of atoms. Electrons in metals are not held tightly to the nucleus and can move in metals. Electrons move in wires that are part of closed circuits.

Generator

A generator is a device that transforms energy of motion into electrical energy. In a generator, a coil and magnetic field move relative to each other. This movement produces or generates electricity in the coil. The generated electricity is sent over power lines to homes, schools, and businesses.

Interaction

Interaction occurs when objects do something to each other. When a bat strikes a ball, the ball and bat hit each other and therefore interact. When a magnet is moved near an iron object, the magnet and iron object attract each other and therefore interact. Magnets, whether permanent magnets or electromagnets, can interact (attract and repel) with each other.

Mag-lev Trains

Mag-lev trains are trains that do not touch the track as they move along. The train is both held off the track (levitated) and propelled down the track by strong electromagnets. Without the friction of wheels rolling alone a track, the mag-lev trains can move very fast (over 300 miles per hour), very smoothly, and with little pollution. Scientists and engineers are experimenting with these magnetic levitation (mag-lev) trains.

Magnetic Field

The magnetic field is the region or space around an object where there is a magnetic effect. A magnetic effect is the attraction of iron or the attraction and repulsion of a magnet. A magnet, a current-carrying wire, and a moving charged particle produce magnetic fields around them.

Magnetism

Magnetism is the property of attracting iron or steel objects.

Non-conductor

A non-conductor is a material that electricity or an electrical current does not easily pass through. Non-metals are usually good non-conductors. Another name for "non-conductor" is "insulator." An insulator keeps electricity from passing from one object to another object.

Open Circuit

An open circuit is a circuit that has a non-conductor (air or other non-conductors) in the path that runs to and from the power source.

Rotor

The rotor is a part of a machine that rotates or spins around and does work. The interaction of magnets makes the rotor spin around in an electric motor.

Short Circuit

A short circuit is a closed circuit that presents little resistance to the flow of electricity. A short circuit is therefore an "easy" circuit. A copper or aluminum wire connecting one end of a battery to the other end of a battery produces a short circuit. Short circuits often heat up wires, which can cause burns or fires.

Superconductors

Superconductors are electrical conductors that offer little or no resistance to the flow of electricity. At the present time, superconductors exist only at very low temperatures.

Voltage

To get charges to move in conductors, the charges have to be pushed. Voltage is a measure of how hard the charges are pushed. When the voltage is high, the charges are given a big push and carry lots of energy. When the voltage is low, the charges are given a small push and carry a little energy. In a circuit, when the voltage is increased, the current increases if everything else stays the same.

CHARGING AHEAD

An Introduction to Electromagnetism

Charging Ahead: An Introduction to Electromagnetism is a set of hands-on activities designed to help teachers introduce middle and high school students to electromagnetism, one of the most fascinating and life changing phenomenon humankind has witnessed. In 1820, Hans Oersted, a Danish physicist and school teacher, discovered that an electrical current produces magnetism. This set the stage for the development of the electrical motor and the discovery of ways of generating electricity from motion and magnets.

Charging Ahead uses readily available materials to introduce students to electromagnetism, to the factors that determine the strength of electrical coils, to the application of electromagnetism in the construction of an electrical motor, and to the production of electricity through the construction of a generator. Throughout **Charging Ahead**, students are introduced to historical perspectives and to technological applications (circuit breakers, mag-lev trains, superconducting generators, etc.). **Charging Ahead** is a companion to NSTA's **Taking Charge: An Introduction to Electricity.**

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